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Advanced Graduate Leadership Program Gives Students a Leg Up

Microbial Diversity

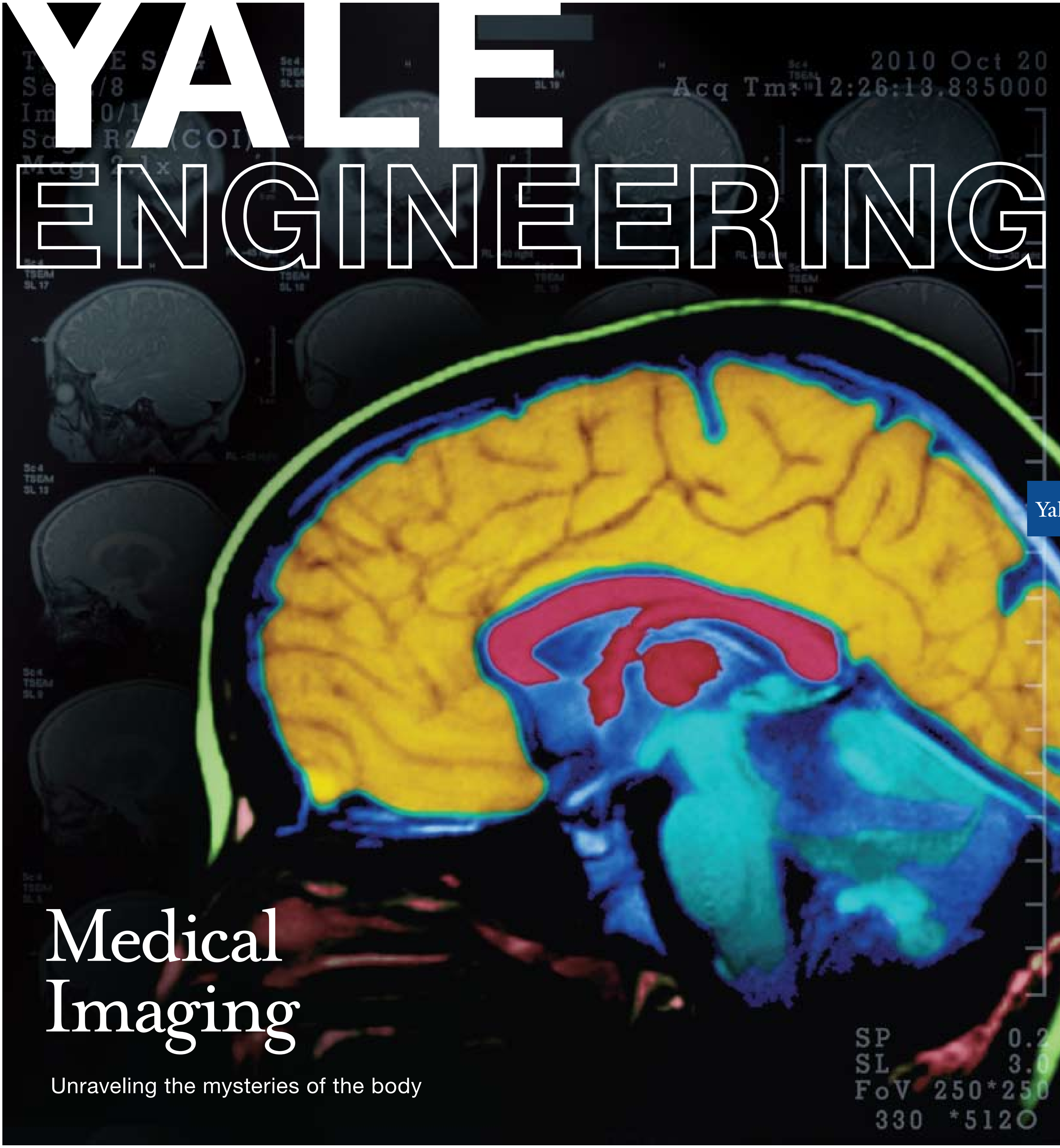
From Genetic Sequencing to Biofuels

Back on the Track

Yale Bulldogs Racing Team Drives to Success

2010

YALE ENGINEERING



Medical Imaging

Unraveling the mysteries of the body

The Publication of Yale's School of Engineering & Applied Science

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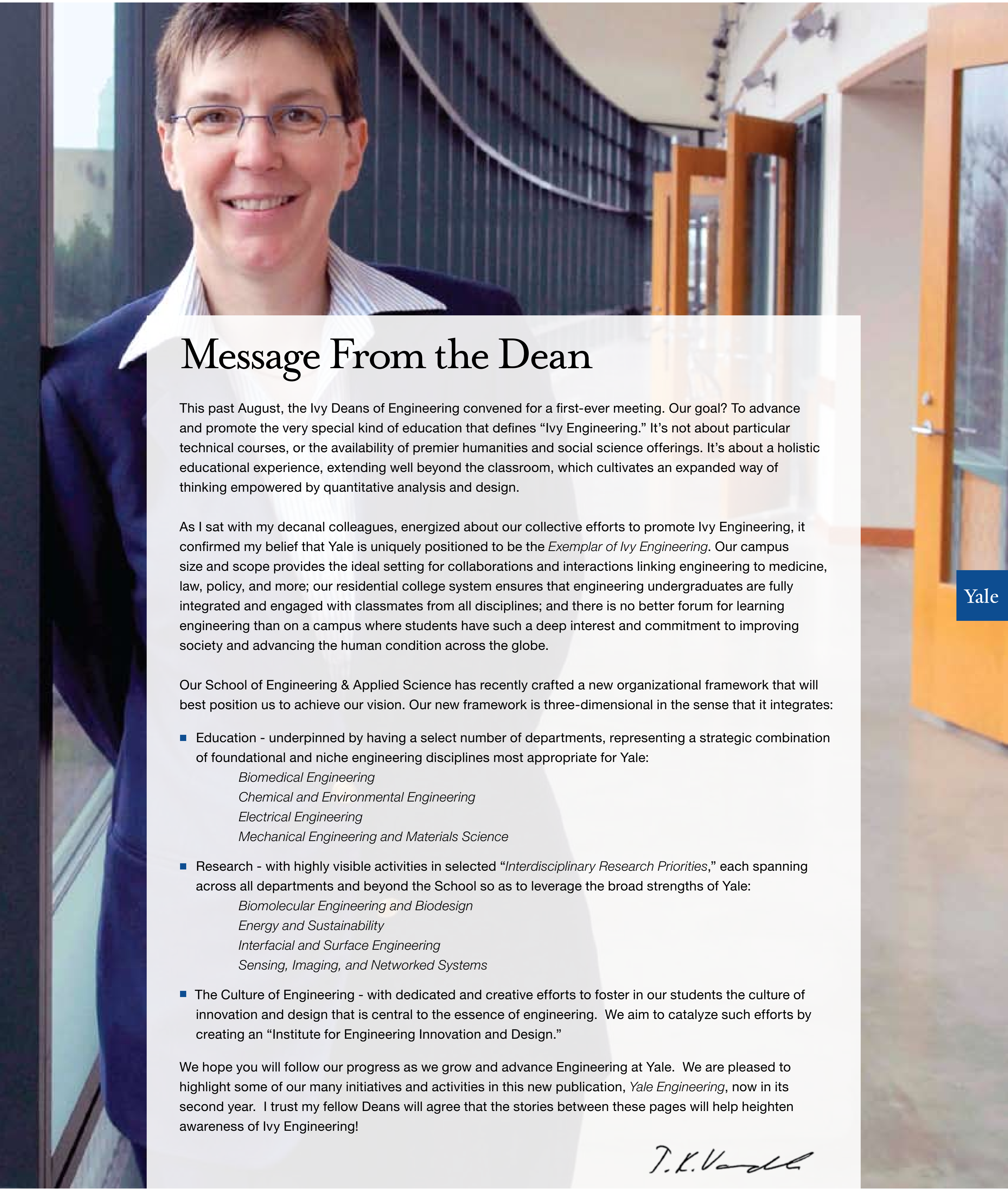


Message From the Dean

This past August, the Ivy Deans of Engineering convened for a first-ever meeting. Our goal? To advance and promote the very special kind of education that defines “Ivy Engineering.” It’s not about particular technical courses, or the availability of premier humanities and social science offerings. It’s about a holistic educational experience, extending well beyond the classroom, which cultivates an expanded way of thinking empowered by quantitative analysis and design.

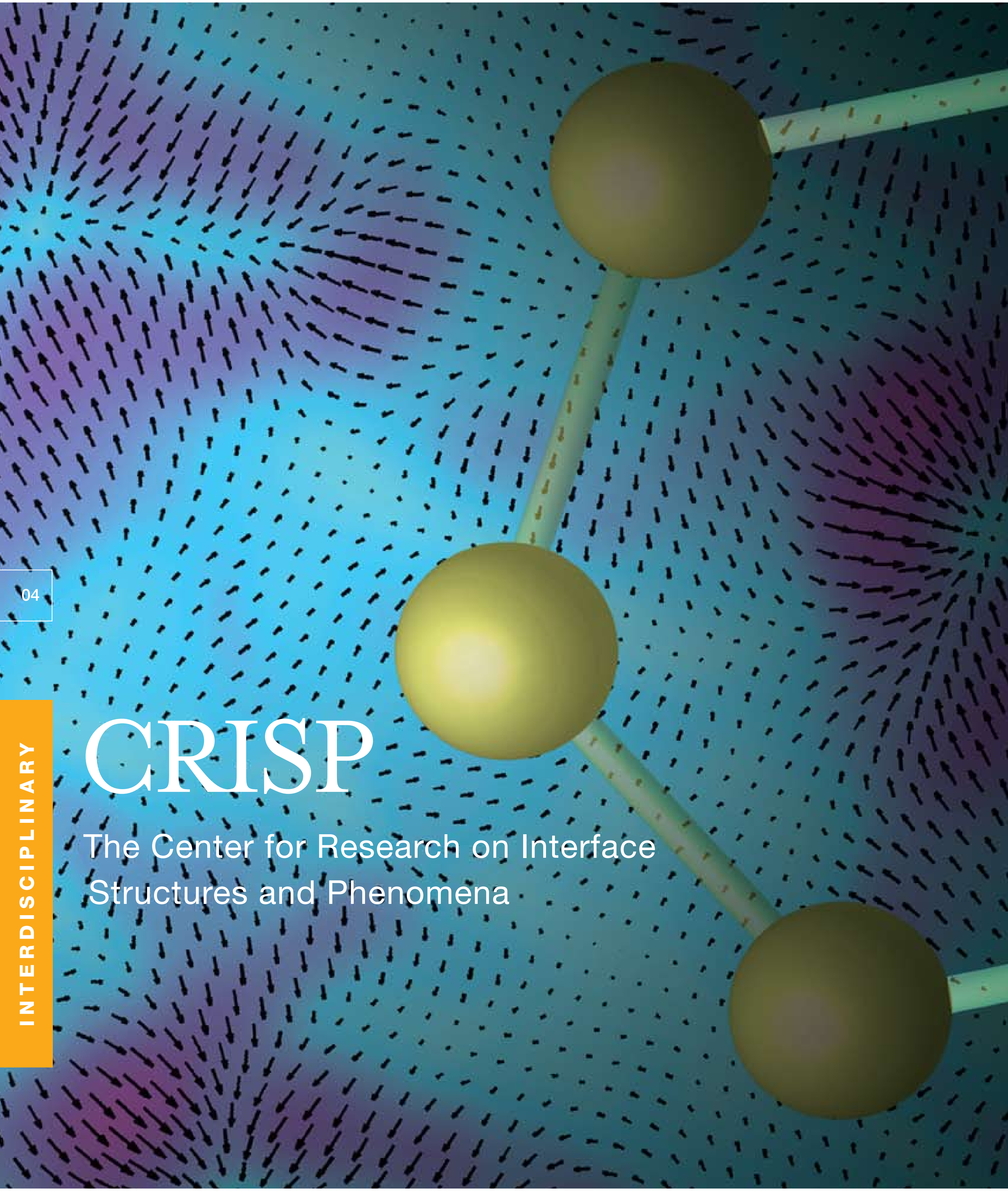
As I sat with my decanal colleagues, energized about our collective efforts to promote Ivy Engineering, it confirmed my belief that Yale is uniquely positioned to be the *Exemplar of Ivy Engineering*. Our campus size and scope provides the ideal setting for collaborations and interactions linking engineering to medicine, law, policy, and more; our residential college system ensures that engineering undergraduates are fully integrated and engaged with classmates from all disciplines; and there is no better forum for learning engineering than on a campus where students have such a deep interest and commitment to improving society and advancing the human condition across the globe.

Our School of Engineering & Applied Science has recently crafted a new organizational framework that will best position us to achieve our vision. Our new framework is three-dimensional in the sense that it integrates:

- Education - underpinned by having a select number of departments, representing a strategic combination of foundational and niche engineering disciplines most appropriate for Yale:
  - *Biomedical Engineering*
  - *Chemical and Environmental Engineering*
  - *Electrical Engineering*
  - *Mechanical Engineering and Materials Science*
- Research - with highly visible activities in selected “*Interdisciplinary Research Priorities*,” each spanning across all departments and beyond the School so as to leverage the broad strengths of Yale:
  - *Biomolecular Engineering and Biodesign*
  - *Energy and Sustainability*
  - *Interfacial and Surface Engineering*
  - *Sensing, Imaging, and Networked Systems*
- The Culture of Engineering - with dedicated and creative efforts to foster in our students the culture of innovation and design that is central to the essence of engineering. We aim to catalyze such efforts by creating an “Institute for Engineering Innovation and Design.”

We hope you will follow our progress as we grow and advance Engineering at Yale. We are pleased to highlight some of our many initiatives and activities in this new publication, *Yale Engineering*, now in its second year. I trust my fellow Deans will agree that the stories between these pages will help heighten awareness of Ivy Engineering!

Yale



CRISP

The Center for Research on Interface Structures and Phenomena

For many materials scientists and applied physicists interactions at the interface between two different materials is where the excitement is. Long gone are the days when electronics manufacturers assembled materials together by hand. Today's materials are sandwiched together with atomic-scale precision—an advancement that has led to the control of exotic solid-state phenomena, such as magnetism and superconductivity at the nanoscale, and a promise of applications that will have broad-sweeping impact on future technologies.

In 2005, the National Science Foundation awarded a six-year, $7.5 million grant to establish a Materials Research Science and Engineering Center (MRSEC) at Yale, known as the Center for Research on Interface Structures and Phenomena, or CRISP. Since that time, a multidisciplinary group of mechanical, electrical and chemical engineers, physicists, applied physicists, and chemists—comprised of both theorists and experimentalists—has produced some of the leading research in the world on atomically engineered materials and interfacial phenomena. Some of the Yale work in these areas was recently featured in the July 2010 issue of *Advanced Materials*, which was solely dedicated to CRISP research.

Their primary focus revolves around crystalline oxides—common compounds that exhibit nearly every possible effect seen in solid-state physics, ranging from magnetism to superconductivity. Because of their lattice structure, crystalline oxides of different chemical composition are easy to stack, allowing for atomic-scale sandwiching of a variety of materials. Of course, "easy" is a relative term. It can take up to a few years just to figure out how to construct such structures and their intricate assembly requires expensive equipment that can create the ultra-clean vacuum of outer space needed to protect these delicate structures from contamination.

That is not a problem for CRISP, which houses four oxide molecular beam epitaxy (MBE) machines, sophisticated vacuum systems that grow materials a single atomic layer at a time. Any research institute would be fortunate to have one of these machines, let alone four.

Given the amount of time it takes to engineer oxide interfaces, there is always a backlog of experiments. Fortunately, CRISP experimentalists can rely on a team of high-powered theorists for predictions and direction—something that could not be done 10 or 15 years ago.

In addition to complex oxide interface research, CRISP has recently formed an interdisciplinary team to explore the optics of amorphous nanostructures, inspired in part by the striking colors of the feathers of certain birds. Not all colors in the animal kingdom are resultant of pigments. In the case of some birds, the vivid colors are the result of light scattering off of nanostructures. Understanding how these structures are formed and using this knowledge to fabricate artificial structures with desired properties could lead to a variety of applications.

The Yale Center for Research on Interface Structures and Phenomena is a unique world-class facility that allows teams an ability to pursue interdisciplinary research. Over 23 faculty members from 8 different departments collaborate at CRISP to synthesize and characterize thin film materials with atomic precision. The Center has already yielded significant results which have contributed to advancements in high performance electronics, surface chemistry, lasers, biological materials and science education. Continued investigation and research will undoubtedly lead to more discoveries and applications.

Competitive Advantage

Advanced Graduate Leadership Program Gives Students a Leg Up

Front row (Left to Right) *Fang Fang, Alp Kucukelbir, John Onofrey, Codruta Zoican, Changchang Liu, Tarek Fadel*
Back row (Left to Right) *Rachel Fields, Andreas Fragner, Nan Li, Jason Park, Xiaoming Wang*
Not pictured *Sarah Miller*

When the School of Engineering & Applied Science launched the Advanced Graduate Leadership Program in the fall of 2009, it introduced a new paradigm in graduate education that would reshape the way many Yale Engineering graduate students thought about their studies.

For many, the traditional model for graduate education is limited. It directs students to focus exclusively and narrowly on a research problem, failing to provide the interdisciplinary preparation that is needed to fully address today's complex problems. "Today's leaders must be able to cross the boundaries of science, policy, and business," says Dean Vanderlick, whose vision for the Leadership Program extends beyond preparing tomorrow's leaders to attracting high caliber students to Yale's graduate program. "We know a large number of our students go on to careers in industry and business, where this will be of great value, but even those who remain in academia will benefit tremendously from expanding their knowledge base, research capabilities, interdisciplinary partnerships, and communications and outreach skills—all necessary for a successful career in academics."

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The Advanced Graduate Leadership Program provides highly motivated doctoral candidates with relevant and valuable experiences and avenues for success across the full spectrum of professions that benefit from the expertise of engineers, including academia, industry, business, and policy and public service.

In his address as the Sheffield Lecturer at Yale in 1996, the late Roberto Goizueta, '53, said this of his undergraduate education: "Engineering at Yale is something broader than engineering at any technical institute. The beauty of a formal education in engineering at Yale is that you get the discipline of an engineering curriculum, but you are also provided with the opportunity to stretch your mind in other directions. […] And I don't think the importance of that can be overstated…because virtually nothing that I do today is, in the strictest or purest sense, engineering." Goizueta went on to a distinguished career at The Coca-Cola Company, culminating in sixteen years as chairman of the board of directors and CEO.

"What Yale has done exceedingly well for its undergraduates in Engineering, we must also do for our graduate students," says Vanderlick.

In its first year, the program admitted 12 students as "leadership fellows." They were students that demonstrated an aptitude and ability to succeed not only in their dissertation research, but also the capability to take advantage of the opportunities provided by the program.

What began in fall 2009 as an individually-designed four course sequence offered by Yale's School of Management expanded through the year to include highly sought after internships in technology ventures with the Yale Office of Cooperative Research (OCR) and Yale Entrepreneurial Institute (YEI), as well as opportunities in K-12 outreach, communications and public affairs, policy and government relations, and international partnerships.

Pathways to Engineering

On April 23, Sarah Miller, environmental engineering doctoral student and Leadership Fellow, welcomed 20 students from seven area middle schools to Yale Engineering for a Pathways to Engineering Program that she designed to encourage students to pursue interests in science and engineering. From lab experiments to a paper airplane design challenge, Miller and the crew of graduate volunteers she recruited shared their enthusiasm for engineering and provided what participants called an "awesome," "engaging," and "fun" day in Engineering.

"I was excited that the School of Engineering was interested in supporting K-12 educational efforts as well as fostering these interests in SEAS graduate students," says Miller of the Leadership Program

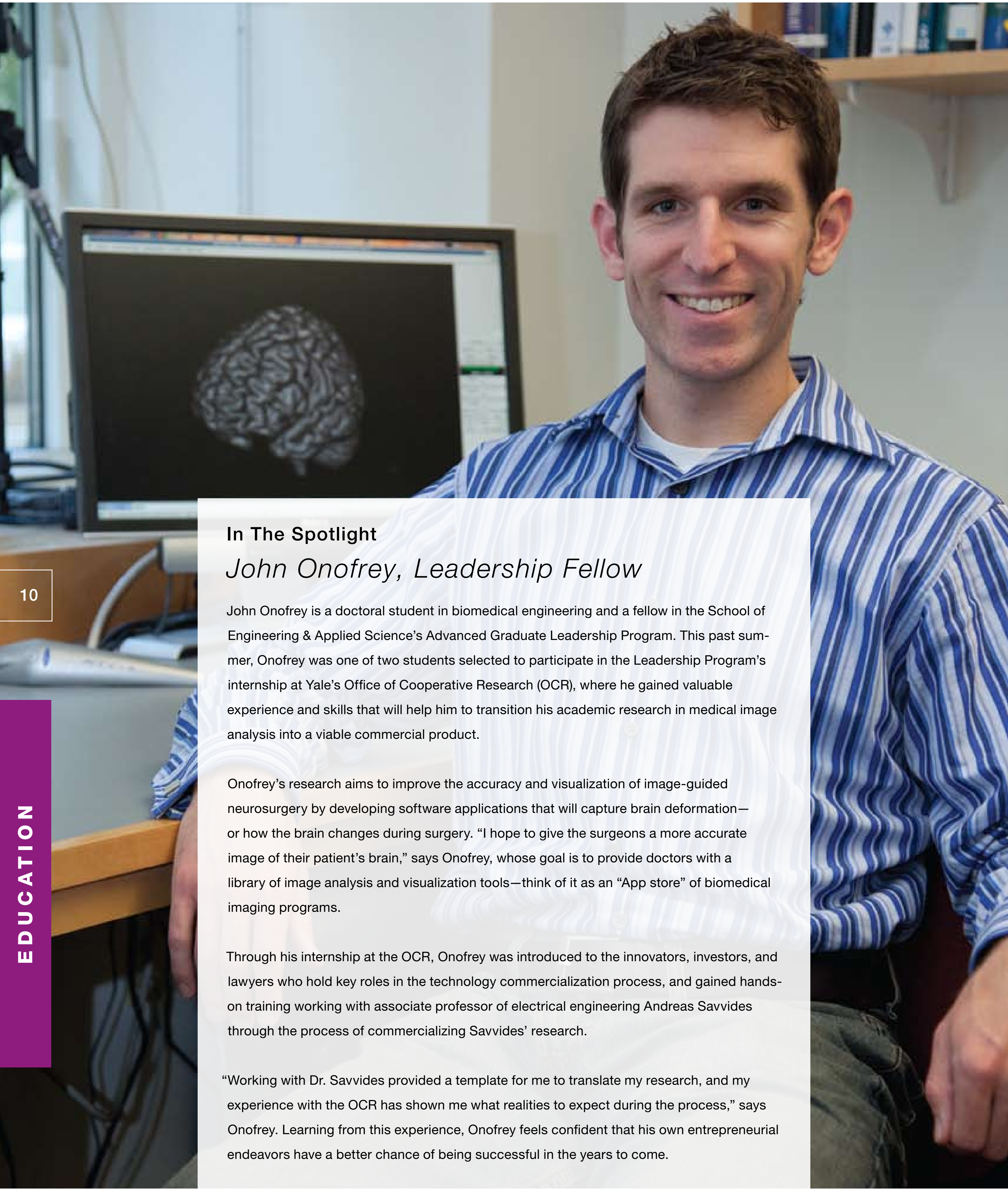
"It's an excellent opportunity for our doctoral students to gain additional experience and insight from experienced mentors and leaders in their respective areas," says assistant professor of mechanical engineering and former engineer of the Segway® Personal Transporter, John Morrell.

The program will continue to grow in the next year and provide its participants with valuable experience beyond the lab. Like the inaugural class, the next Advanced Graduate Leadership Program participants will have the chance "to stretch their minds" and cross the boundaries of science, policy, and business.

Sarah Miller

Prior to attending Yale, Miller worked for two years as a Teach for America (TFA) corps member while earning a master's in education and her California teaching credential in multiple subjects. Miller has long sought and taken advantage of opportunities that bridge her interests in engineering research with public education. In addition to the Pathways program, Miller developed a program in partnership with a local middle school that pairs Yale Engineering graduate students with public school teachers for classroom and curriculum assistance.

Miller has a B.A. in Chemistry from Amherst College and a master's in education from Alliant International University. She came to Yale with a National Science Foundation Graduate Research Fellowship which she has used to develop biomaterials for removing arsenic from water in regions of the world it is most critically needed. "I hope to use science to enrich the lives of underserved populations," says Miller who hasn't yet determined if this will be through academia, public service, or industry. "The underlying dogma of graduate school is 'publish, publish, publish' which typically translates to 'research, research, research,'" says Miller. "While I think that most graduate students at Yale seek balance with extracurricular endeavors, institutional opportunities to diversify one's graduate school experience, such as those provided by the Leadership Program, are especially important."



In The Spotlight

John Onofrey, Leadership Fellow

John Onofrey is a doctoral student in biomedical engineering and a fellow in the School of Engineering & Applied Science's Advanced Graduate Leadership Program. This past summer, Onofrey was one of two students selected to participate in the Leadership Program's internship at Yale's Office of Cooperative Research (OCR), where he gained valuable experience and skills that will help him to transition his academic research in medical image analysis into a viable commercial product.

Onofrey's research aims to improve the accuracy and visualization of image-guided neurosurgery by developing software applications that will capture brain deformation—or how the brain changes during surgery. "I hope to give the surgeons a more accurate image of their patient's brain," says Onofrey, whose goal is to provide doctors with a library of image analysis and visualization tools—think of it as an "App store" of biomedical imaging programs.

Through his internship at the OCR, Onofrey was introduced to the innovators, investors, and lawyers who hold key roles in the technology commercialization process, and gained hands-on training working with associate professor of electrical engineering Andreas Savvides through the process of commercializing Savvides' research.

"Working with Dr. Savvides provided a template for me to translate my research, and my experience with the OCR has shown me what realities to expect during the process," says Onofrey. Learning from this experience, Onofrey feels confident that his own entrepreneurial endeavors have a better chance of being successful in the years to come.

In The Spotlight

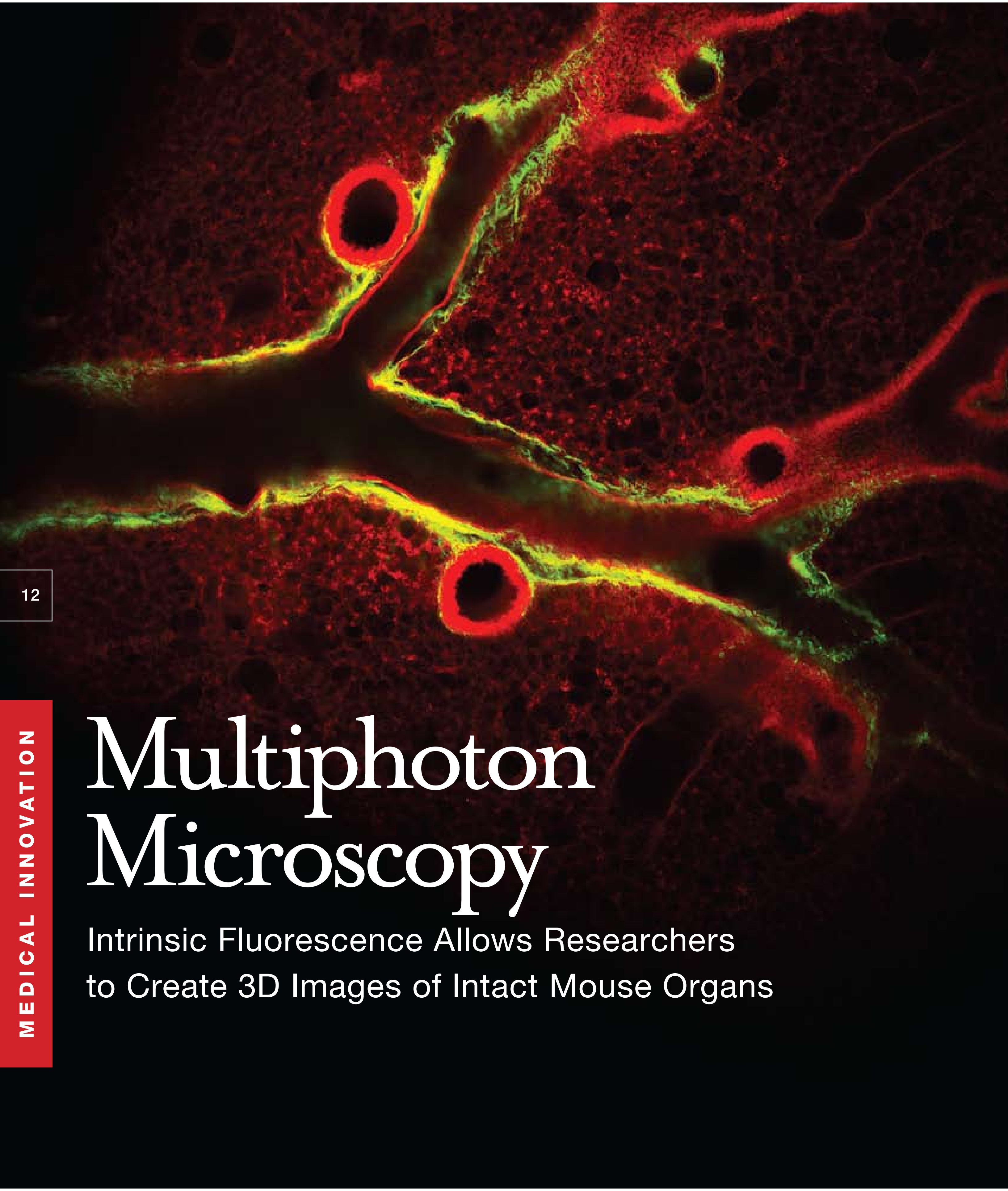
Sonia Parra

Yale Undergraduate Sonia Parra graduated from Health Careers High School in San Antonio, Texas with the dream of becoming a doctor. Had someone told her that she would be first author on a research article appearing in the *Journal of Biomedical Optics*, she would not have believed it or, perhaps, even understood its significance. But, as a junior, she had achieved just that.

At Yale, Parra chose to study biomedical engineering because of the way it uniquely melded her interests in biology, chemistry, and medicine. After her freshman year, she applied to a summer undergraduate internship in the lab of associate professor of biomedical engineering Michael Levene. There she began her first independent research project in fluorescence microscopy and optical clearing—techniques that would allow her to be the first to create a 3D model of whole intact mouse organs (published in the May/June 2010, issue of the *Journal of Biomedical Optics*).

Upon graduating from Yale next spring, Parra plans to spend a year pursuing research interests in multiphoton microscopy for tissue engineering before entering an M.D./Ph.D. program. Her ultimate aspiration is to become a transplant or reconstructive surgeon, a profession to which she hopes to apply the tools of her research.

Read more about Sonia's work on the next page in ***"Multiphoton Microscopy"*** →



Multiphoton Microscopy

Intrinsic Fluorescence Allows Researchers to Create 3D Images of Intact Mouse Organs

Associate professor of biomedical imaging Michael Levene and undergraduate Sonia Parra have, for the first time, created 3D models of whole intact mouse organs. Combining an imaging technique called multiphoton microscopy with "optical clearing," which uses a solution that renders tissue transparent, the researchers were able to scan mouse organs and create high-resolution images of the brain, small intestine, large intestine, kidney, lung and testicles. They then created 3D models of the complete organs—a feat that, until now, was only possible by slicing the organs into thin sections or destroying them in the process, a disadvantage if more information about the sample is needed after the fact.

With traditional microscopy, researchers are only able to image tissues up to depths on the order of 300 microns, or about three times the thickness of a human hair. In that process, tissue samples are cut into thin slices, stained with dyes to highlight different structures and cell types, individually imaged, then stacked back together to create 3D models. By contrast, the Yale team, which also included graduate students Thomas Chia and Joseph Zinter, was able to avoid slicing or staining the organs by relying on natural fluorescence generated from the tissue itself.

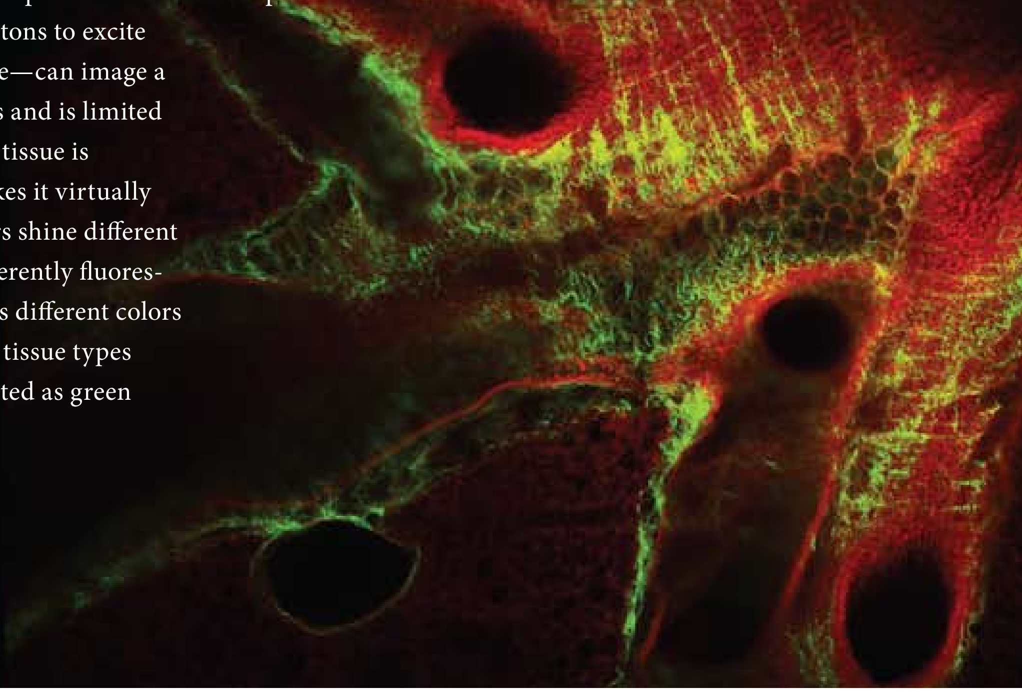
When combined with optical clearing, multiphoton microscopy—so called because it uses photons to excite naturally fluorescent cells within the tissue—can image a larger field-of-view at much greater depths and is limited only by the size of the lens used. Once the tissue is cleared using a standard solution that makes it virtually transparent to optical light, the researchers shine different wavelengths of light on it to excite the inherently fluorescent tissue. The fluorescence is displayed as different colors that highlight the different structures and tissue types (in the lung, for example, collagen is depicted as green while elastin shows up as red).

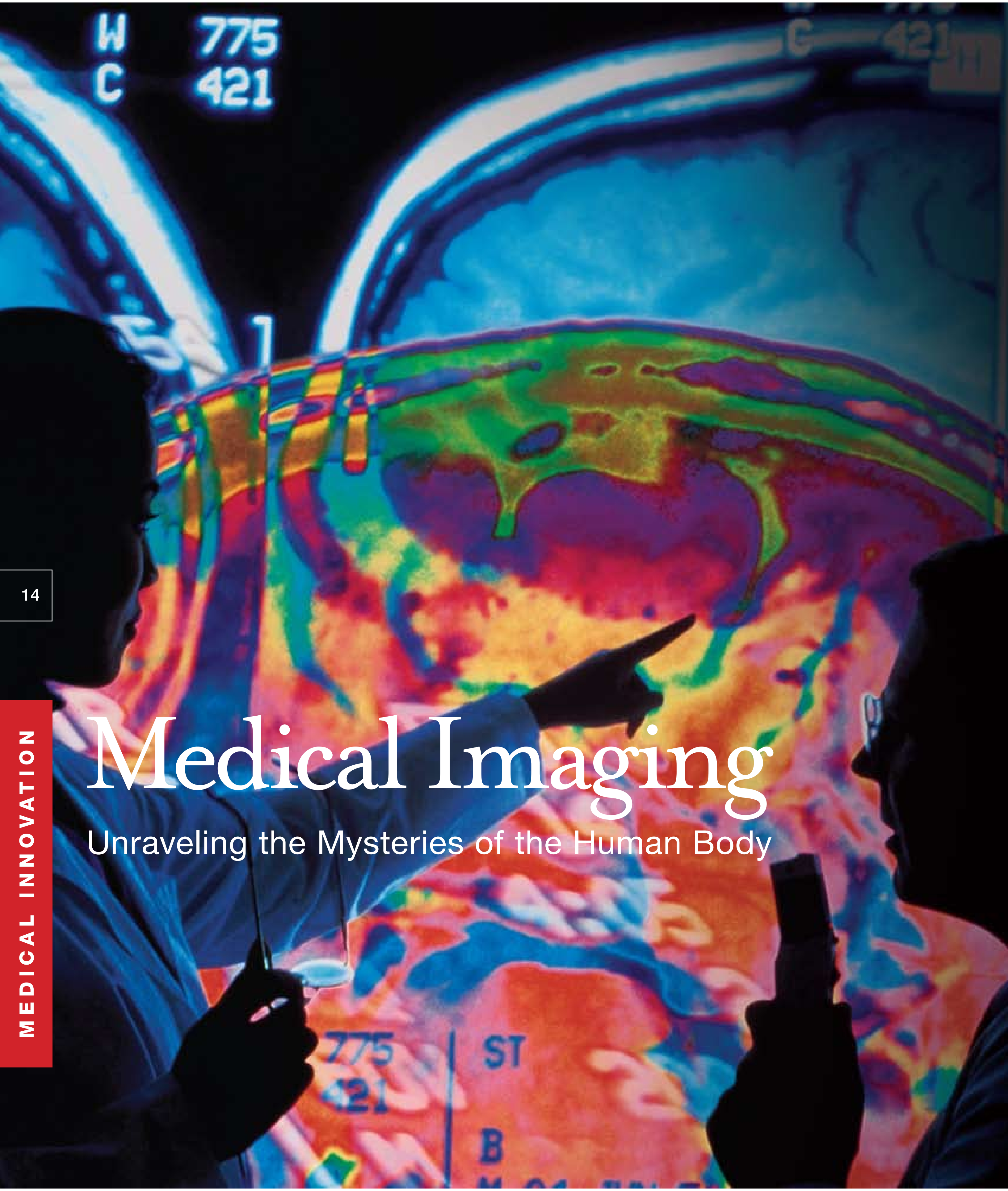
"The intrinsic fluorescence is just as effective as conventional staining techniques," said Levene. "It's like creating a virtual 3D biopsy that can be manipulated at will. And you have the added benefit that the tissue remains intact even after it's been imaged."

The Yale team was able to reach depths in excess of two millimeters—deep enough to image complete mouse organs. Typical tissue samples taken during patient biopsies are about this size as well, meaning the new technique could be used to create 3D models of biopsies, Levene said. This could be especially useful in tissues where the direction of a cancerous growth may make it difficult to know how to slice tissue sample, he noted.

In addition, the technology could eventually be used to trace fluorescent proteins in the mouse brain and see where different genes are expressed, or to trace where drugs travel in the body using fluorescent tagging, for example.

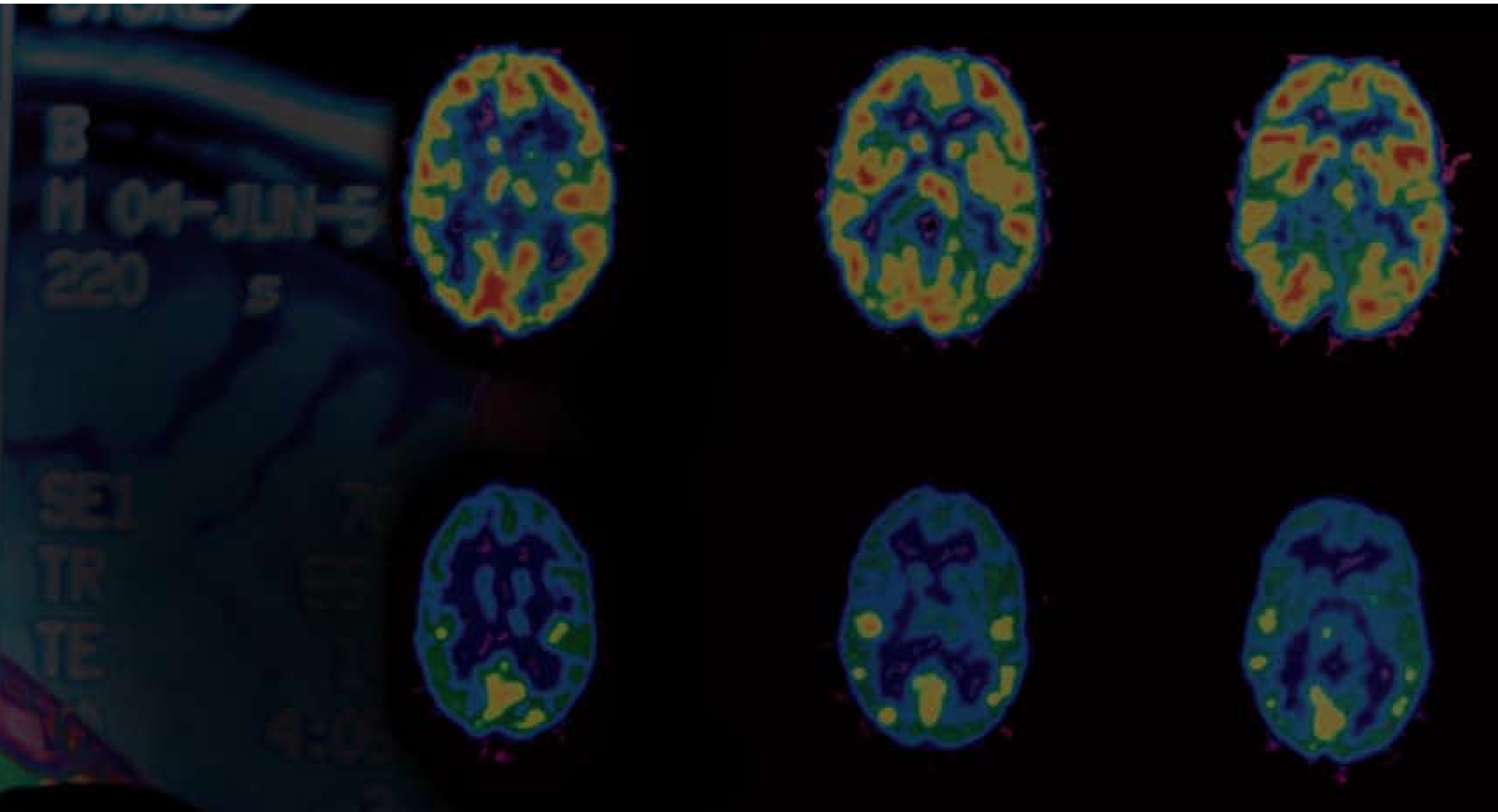
"Fluorescence microscopy plays such a key role throughout biology and medicine," Levene said. "The range of applications of this technique is immense, including everything from improved evaluation of patient tissue biopsies to fundamental studies of how the brain is wired."





Medical Imaging

Unraveling the Mysteries of the Human Body



Since the advent of the x-ray in the late 1800s, imaging has become an essential component of medical practice and research and has vastly expanded our view of the human body—particularly in the past 30 years.

In 1986, Yale scientists, recognizing the enormous potential possible in biomedical research with the emergence of magnetic resonance, established the Magnetic Resonance Research Center (MRRC). Yale's MRRC is one of the largest centers worldwide, occupying 33,000 square feet of dedicated research space to develop and apply state-of-the-art magnetic resonance (MR) imaging and spectroscopy technologies.

Today, the MRRC is one of several imaging research centers at Yale dedicated to revealing the mysteries of the human body. With the addition of the Positron Emission Tomography (PET) Center, the Optical Imaging Center, and the Center for Cellular and Molecular Imaging (CCMI), Yale researchers are at the forefront of exploring and understanding biological structure and function—ranging from macroscopic views of the whole body to microscopic structures of proteins.

Their work covers cardiovascular disease to Alzheimer's and like much of Yale's scientific research, is highly collaborative with partnerships that extend beyond the Yale medical and science communities.

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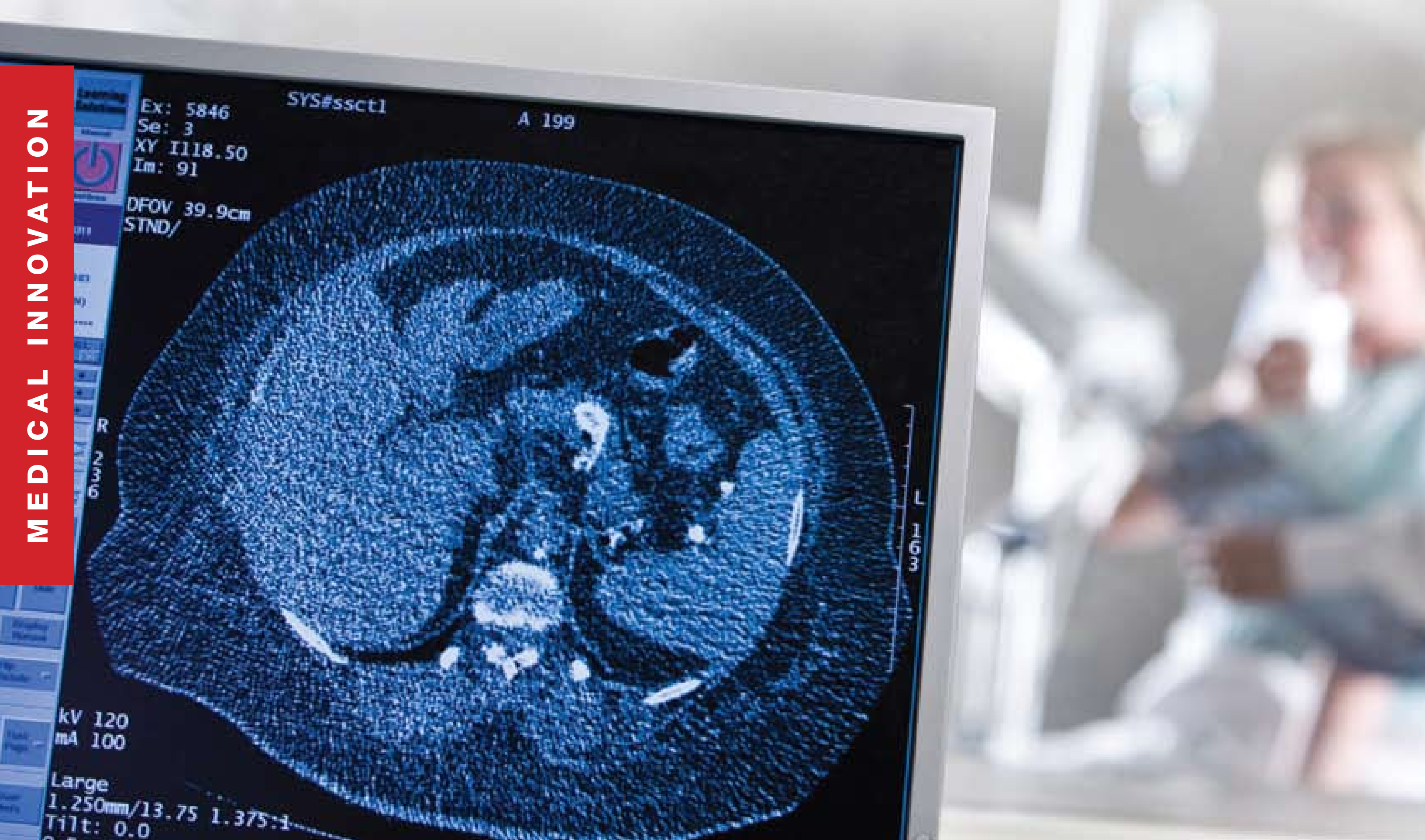
Magnetic Resonance Imaging (MRI) and Spectroscopy (MRS)

Co-directed by professors of biomedical engineering Todd Constable and Douglas Rothman, the Yale MRRC provides a state-of-the-art research set up, which includes eight horizontal-bore magnets, for in vivo MR research. A significant advantage of MRI over other imaging methods is that it does not require radiation. Instead, MRI technology relies on the magnetic properties of certain molecules, predominantly water, to provide a detailed visualization of the body's internal structure and in many specialized cases even function.

In the early 1990s, research expanded from structural imaging to tracking blood oxygenation, a technique enabled by the divergent magnetic properties of oxygen-rich and oxygen-poor hemoglobin in blood affecting the water MRI signal. Since then, functional MRI (fMRI) has become the dominant research tool for mapping brain activity, marked by increased levels of oxygenated blood to regions of increased neural function.

With fMRI, researchers have been able to "see" that the delivery of oxygenated blood increases to particular areas of the brain when a person is asked to perform a task, such as tapping their fingers. The precise relationship between blood flow and neural activity, however, is only slowly being understood. According to Fahmeed Hyder, professor of biomedical engineering and director of the Core Center for Quantitative Neuroscience, the question stands as whether or not the blood oxygenation-based change really represents the function of neural cells, and if it does whether it can be accurately measured and applied to clinical diagnoses such as epilepsy and Parkinson's.



One method that has been particularly useful in this effort is MR spectroscopy (MRS), which provides extraordinary biochemical information of neural cells. Yale's MRS work is most well known for its unique approach of using carbon-13—a non-radioactive, yet MR-detectable isotope of carbon—as a tracer (or label) to study neural cell function in the brain in real time.

"Imagine attaching a label to glucose (the primary sugar metabolized by neural cells, and the body in general)," says Hyder "and seeing the fate of that label all the way through its metabolism." This carbon-13 MRS method, advanced greatly by Rothman and other Yale colleagues, has appreciably changed the way people think about energy metabolism in the brain and has helped Hyder and researchers all over the globe better understand the relationship between blood flow and neural activity.

Beyond tracking glucose, Hyder's laboratory has begun novel work developing a new class of MR contrast agents (or dyes) that can be imaged directly with MRS, as opposed to indirectly imaging the dye's effect on water molecules by MRI. Currently, his is the only laboratory using high-speed MRS techniques for molecular imaging, which they believe will improve specificity for tracking disease and function.

Positron Emission Tomography (PET)

The Yale PET Center was founded in 2004 and is one of a small number of PET laboratories in the world dedicated solely to research and with the capability to develop novel PET tracers and techniques.

Like fMRI, PET measures functional processes, such as the metabolic activity of cells. Unlike fMRI, PET uses radioactive molecules to trace biochemical processes in the body. Some of the early studies of brain function in vivo were conducted with PET using a radioactively-labeled sugar analog named fluoro-deoxyglucose (FDG), to measure glucose metabolism (similar to the carbon-13 MRS method previously mentioned). While radiologists today rely on FDG-PET scans as a diagnostic tool for cancer, fMRI, which can be done much faster, much cheaper, and without radioactivity, has taken the lead in imaging brain activity.

"You might think we wouldn't have been happy about that, but it was the best thing to happen to PET," says professor of biomedical engineering and director of the PET Center Richard Carson. "The reason is, we stopped doing studies using simple non-specific molecules, such as radioactive glucose and water, and started using very specific molecules that follow specific biological mechanisms."

In fact, in the past four years, scientists at the Yale PET Center have designed over 45 different tracers—some completely novel—to diagnose disease, determine if a drug is getting to the place in the body where it is most needed, and assess a drug's effectiveness. One example of this is in Alzheimer's disease (AD). While there is

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no single clinical test used to diagnose AD, researchers believe there is a link between it and plaque deposits in the brain. With a specific radioactive tracer that binds to these deposits, in this case molecules of amyloid beta, PET would be able to provide quantitative imaging data of those molecules if they exist, as well as how they respond to drug treatment. Without the specific tracer, this type of measurement in human patients would be impossible.

"I've been doing this for over 30 years," says Carson, "and it is still very exciting. When you make a brand new molecule and trace it through the brain or body, you're able to see an image that's never been seen before. If you can make sense of it, it's even better."

Optical Imaging

A relatively new collaborative effort at Yale is in the area of optical imaging, bolstered by the formation of the Optical Imaging Center in 2010.

Michael Levene, associate professor of biomedical engineering, is pushing the limits of century-old optical microscopy to image deeper into the body. Using needle-like lenses, Levene probes and images the cerebral cortex of living mice. Traditionally, scientists have only been able to optically image about 5% of the mouse brain, unable to reach the deeper layers of the cortex where brain processes relating to thought, memory and awareness take place. Levene hopes to image the remaining 95% of the mouse brain by improving the optics of his lenses and employing a prism-lens combination—similar to a periscope—that can image cells undamaged by the needle in their native environment.

By imaging living mice, these new techniques will allow researchers to navigate blood vessels in the brain and image neural activity in real time. "That kind of knowledge would be useful in a wide range of applications," says Levene, "from the design of better drug delivery systems to understanding the role genes play in diseases affecting the brain, such as Parkinson's and Alzheimer's."

Cryogenic Electron Microscopy

Another technology with great promise for sub-molecular biomedical research is a special type of microscopy called cryogenic electron microscopy, or Cryo-EM for short. Cryo-EM allows researchers to understand the physical three-dimensional (3D) structure of proteins, which are directly connected to their function in the human body.

"Cryo-EM is just like conventional electron microscopy, except that the specimen is held at very, very low temperatures to lock their positions," explains Fred Sigworth, co-director of the Center for Cellular and Molecular Imaging and professor of biomedical engineering. Because proteins can be as small as half a nanometer—a million times smaller than a pinhead—inhibiting movement is crucial for imaging.

In 2009, Yale's Sterling Professor of Molecular Biophysics and Biochemistry, Thomas Steitz, received a Nobel Prize in Chemistry for work describing the structure and function of the ribosome—the protein-making factory of the body. This is the real interest in cryo-EM, but it is not easy. In fact, reconstructing 3D structures of protein complexes from two-dimensional Cryo-EM images is a significant image processing and computational challenge.

Cryo-EM images are very noisy, and over tens of thousands images are needed for reconstruction. "It takes so long, it is virtually impossible to reconstruct a particle accurately using desktop computers," says Hemant Tagare, associate professor of biomedical engineering. Tagare and Sigworth are working toward developing algorithms that will bring the computing time down to "a matter of days, on a computer you can buy on a budget," says Tagare.

This will increase the rate of sub-molecular discoveries such as Steitz's, as sub-molecular research groups around the world will be able to speedily, and accurately, determine the 3D structures of proteins and small particles.

Image Analysis

With each faculty member contributing their own biological or technological expertise, the breadth of Yale's medical imaging research is great. The scope is even wider, however, as a result of collaborative research where imaging modalities are combined and additional insights are realized.

Collaborations like this are made possible through the Image Processing and Analysis Group (IPAG), a group of cross-disciplinary researchers working to bridge areas of general medical image processing and computer vision with medical imaging specific knowledge. Led by James Duncan, Ebenezer K. Hunt Professor of Biomedical Engineering and Vice Chair of Bioimaging Sciences, IPAG provides a unique service to the medical research community at Yale, allowing engineers to investigate and solve challenges in the medical community at early stages of research.

"Imaging is central. It's central to medicine; it's central to biomedical engineering and, in fact, you couldn't do biomedical engineering in general without it," says Chair and Goizueta Foundation Professor of Biomedical Engineering Mark Saltzman. Medical imaging at Yale is continuously expanding with the addition of new technologies, industry partnerships, and interdisciplinary collaborations devoted to providing cutting-edge medical research and technology advancement. It is clearly one of the great strengths of Yale, the Medical School, and the Department of Biomedical Engineering.

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Microbial Diversity

From Genetic Sequencing to Biofuels

Technology advances have accelerated discovery in many disciplines, including the physically small domain of microbial diversity. As one example, Jordan Peccia, associate professor of environmental engineering and member of the faculty advisory committee for the newly established Microbial Diversity Institute, has come to rely on technological breakthroughs in gene sequencing for his work in biosolids (sewage sludge), indoor aerosols, and algal biofuels. Sequencing that cost $10,000 in the late 1990s costs only $1 today—a development that has opened the door to a whole new wave of research.

Twenty-five years ago, what scientists knew about microbial diversity was limited primarily to the microbes they could grow on an agar plate. It turned out that this represented a very, very small minority of the microbial population—in fact, around 0.1% of the total microorganisms that populate our world.

It wasn't until the late 1970's, that Carl Woese, Ph.D. '53, pioneered a technique for classifying microorganisms by their genetic makeup—16s rRNA gene sequencing—which has become the standard practice for identifying bacteria. This changed everything. For the first time, scientists were able to understand just how big the microbial world was.

The technology, however, has been limited by cost and labor until very recently. Driven by personalized medicine and the goal of being able to tailor health-care to a person's unique genetic makeup, today's rapid DNA sequencing techniques have exponentially dropped in price and increased in capability. This has enabled everyone from microbiologists to environmental engineers to conduct research that was largely unthinkable only a decade earlier.

With the whole world of microbial ecology to explore, characterize and harness, in 2009, Yale established the Microbial Diversity Institute (MDI)—the first of its kind—to engage a diverse array of research interests around this common language.

"Scientists from several fields, even many outside of biology, have come to understand that microbes rule the world," says Howard Ochman, professor of ecology and evolutionary biology and director of the MDI. Ochman and evolutionary biologist, Nancy Moran, were recruited from the University of Arizona to develop and lead the Institute, which is housed on Yale's West Campus and expected to expand to ten new faculty members over five years.

"We want people who know a little about diversity—non-standard microorganisms, evolutionary biology, how communities come together, and how they are functioning—and people who are looking at applying new technologies," says Ochman. It is these new technologies that are creating an unprecedented amount of data and providing entirely novel ways to address scientific questions, according to Vice President for West Campus, Michael Donoghue.

Currently, West Campus has state-of-the-art facilities for high-throughput screening, small molecule screening, and genome analysis. "The MDI will be making fundamental discoveries about microbial life and elucidating the key roles played by microbes in the environment and human health," says Donoghue.

Jordan Peccia has been able to capitalize on these advancements in technology to create a broad portfolio of microbial diversity research, which includes explorations in biosolids, indoor aerosols, and biofuels.

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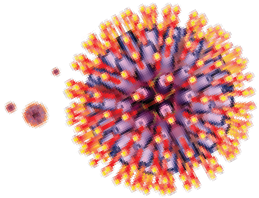
Yale



Biosolids

In 1988, the U.S. government banned ocean disposal of domestic sewage sludge, which spurred the Environmental Protection Agency (EPA) to look for sustainable options for reuse. Today, 60% of the nearly 8 million dry tons of treated domestic sewage sludge, termed "biosolids," produced each year is applied to agricultural lands as soil amendments—a practice the EPA has deemed safe. Health complaints from residents living near application sites, however, raise concern that this practice may present hazardous human exposure to pathogens.

According to Peccia, the EPA's standards for ensuring safe land application of biosolids were developed for "environmental regulation expedience"—meaning they were based on the best available technologies, best knowledge, and available funding at the time. "The EPA didn't know the pathogen content of biosolids, how many and what types of pathogens were present, how it becomes aerosolized, how it moves into a house and out of a house, or how a person responds to it," says Peccia.

Standard practice has involved testing for known pathogens only, such as e-coli. The reality is a single gram of sludge holds 100 billion bacteria. Unfortunately—or fortunately, depending on how you look at it—it takes 100,000 to 1,000,000 identifications to get to a pathogen. "This level of identification was off the table until two years ago," says Peccia. With massively parallel DNA sequencing, developed by Jonathan Rothberg, Ph.D. '91, at 454 Life Sciences in Branford, Connecticut, Peccia says what was once impossible can now be done.

Kyle Bibby, doctoral student and 2010 recipient of an EPA STAR Fellowship for his research on biosolids, recently

demonstrated that they could get 250,000 sequences and could go up to a billion sequences if they were to do it again. As of now, however, their interest has shifted to viruses. They are the first to identify the herpes virus in biosolids as well as over 100 other viruses.

Biosolids is a large industry and their use has created a polarized debate. Peccia's group has refused to choose sides in the ongoing debate, focusing instead on using the scientific tools available to fill in the data that the EPA was missing when it first developed its standards. "We have strong arguments for sterilizing biolosolids," says Peccia. "Perhaps, when people see a list of what's in there, there will be more pressure to do so. Eventually, the EPA is going to have to take this on again and make a decision. We hope our science plays a role."

Indoor Aerosols

Taking advantage of technological advancements in quantitative polymerase chain reaction (qPCR), doctoral student Denina Hospodsky and postdoctoral associates Jing Qian and Naomichi Yamamoto have been investigating microorganisms in air. While much research has been conducted on indoor aerosols, limited research has been conducted on biological indoor aerosols. Using qPCR, the researchers are able to detect and quantify targeted DNA sequences.

The group has been monitoring the air in a classroom at Yale to see how it changes with student presence, ventilation, carpet, and other possible contributing factors. By identifying the microbial populations outside of the classroom, in ventilation ducts, on the classroom floor, and even on the students, and comparing them to what they find in

the air, they can begin to look for matches—for instance, what is in the air may closely resemble what is in the carpet as opposed to that in the HVAC system.

"It's hard to get a real estimate of what the risk might be, but it's easy to determine what can be done to mitigate risk," says Peccia.

With mathematical modeling, the group has begun to investigate the sources, transport, and fates of indoor biological aerosols, including pathogens. "I think the results that we get here are going to be very important to public health studies in order to understand exposure to diseases that are airborne, particularly in the developing world," says Hospodsky, "where some of these, such as tuberculosis, are a leading cause of death."

The past summer, Hospodsky along with undergraduate students Dana Miller and Sisira Gorthala took their study to a classroom in China, funded through an award from the Yale Global Health Initiative.

Microalgae for Biofuels

The use of algae for energy production is not a new idea and, in fact, has been given more consideration than most people probably realize. While the concept itself is much older, the U.S. began to heavily invest in algae as a source of biodiesel in 1978 with the Aquatic Species Program. While the program was discontinued in 1996, the research has picked up once again with renewed attention on alternative energy sources and competing demands for food crops and biofuels.

Unlike corn, soybeans, and other biofuel crops, microalgae can grow pretty much anywhere in open ponds or closed reactors, requiring very little land, yet producing up to 100 times more oil per acre than soybeans or any other terrestrial oil-producing crop.

They are single-celled organisms that use photosynthesis to convert light energy to biomass, including lipids—or fats—which can be used as biofuel. While it is estimated that there are hundreds of thousands of species of microalgae, not all are equally capable of producing lipids. "People want to genetically modify microalgae for biofuel production," says Peccia. "The problem is, unless you sterilize all of the water going into the reactor, which would require a great deal of energy input, you're going to have to deal with the diversity of algae growing in there."

It's a classic case of survival of the fittest, and in this particular case, that is not the fattest. Creating lipids is an energy intensive process, so those that do it have the disadvantage.

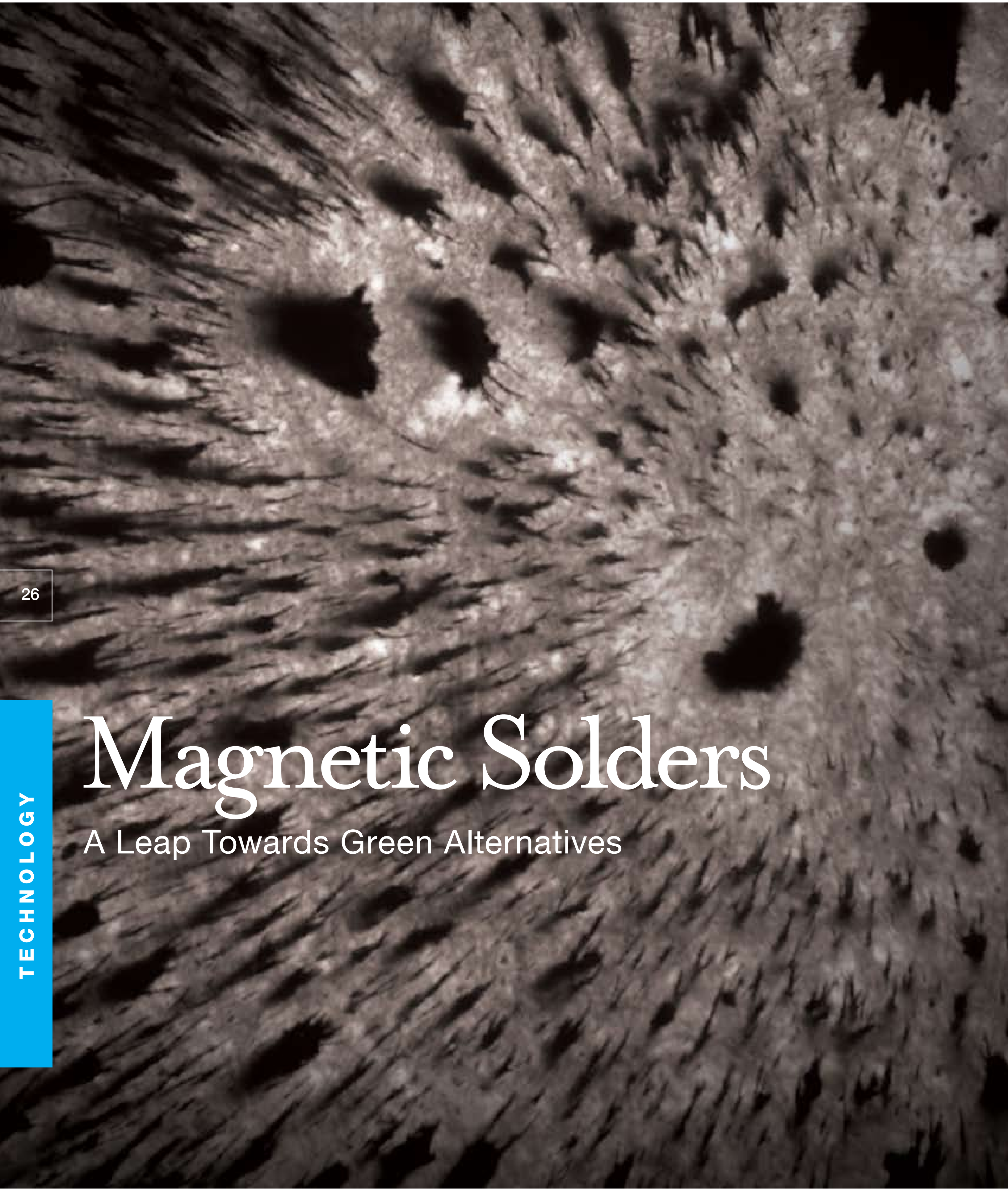
Scenedesmus dimorphus is a species of microalgae that can produce lipids very easily, making it ideally suited for biofuel production. The question is how can they keep the "fat" algae dominant and keep it growing in a reactor that is contaminated by other algal species?

By making genetic libraries of the algae as well as bacteria in the reactor as the growth of S. dimorphus slows and its population eventually crashes, they can begin to piece together what is occurring and investigate the important fundamental questions such as are bacteria scavenging food and which algae species are taking over. If they know what is responsible for the declining population, they may be able to devise a solution.

"We're not completely inadequate in thinking about what might have happened a priori," says Peccia, but today's genetic sequencing tools can help solve the problem.

They have made some progress with their "fat" algae by taking advantage of its high tolerance for carbon dioxide (CO_2). At 20% CO_2—the concentration typically found in flue gas from a power plant—S. dimorphus thrives, while most other species of algae die off. This may be just one means for keeping S. dimorphus dominant.

First-year doctoral student, Allison Retotar, received a 2010 NSF Graduate Research Fellowship to continue this work with the hope that someday soon microalgae may be able to reach its true potential as a sustainable biofuel.



Magnetic Solders

A Leap Towards Green Alternatives

Yale researchers have developed a new type of solder that can be magnetically manipulated in three dimensions and selectively heated, while offering a more environmentally-friendly alternative to today's lead-based solders.

Until recently, virtually all solder—the metal alloy that acts as the glue for bonding microchips and other electronic components—was made from a tin-lead alloy. But concern for the environment, as well as legislation in Japan and the European Union banning the import of electronics with lead solders due to lead toxicity, has increased interest to find a greener alternative.

"We took this as an opportunity to improve solder for the environment, but we also took it as an opportunity to reexamine how to enhance solder in general," said Ainissa Ramirez, associate professor of mechanical engineering. Until now, scientists had difficulty coming up with a suitable alternative for lead-based solders that are just as strong and have a similarly low melting point. Now Ramirez and her team have developed a non-toxic solder made of tin-silver containing iron particles. Not only is using a tin-silver alloy an environmental advantage, the addition of iron particles has other benefits.

First, the iron makes the alloy much stronger than it would ordinarily be. And when an external magnetic field is applied to the molten solder, the iron particles align themselves within the solder, making it even stronger once the solder solidifies.

Second, the iron overcomes the problem of tin-silver having a higher melting point than traditional lead-based solders. By subjecting the solder to an alternating magnetic field, the solder can be selectively heated. This keeps surrounding materials at safe temperatures while melting only the solder itself.

Third, an external magnetic field can be used to remotely manipulate the solder, so it can be moved into hard-to-reach places, such as narrow vertical channels. This means that broken connections within devices can be "self-healed" by applying a magnetic field to melt the solder and re-attach the ends together.

"There is a whole range of possibilities for this new kind of solder," Ramirez said. "In addition to helping make the fabrication of microelectronics more environmentally responsible, these new solders have the potential to solve technological challenges."

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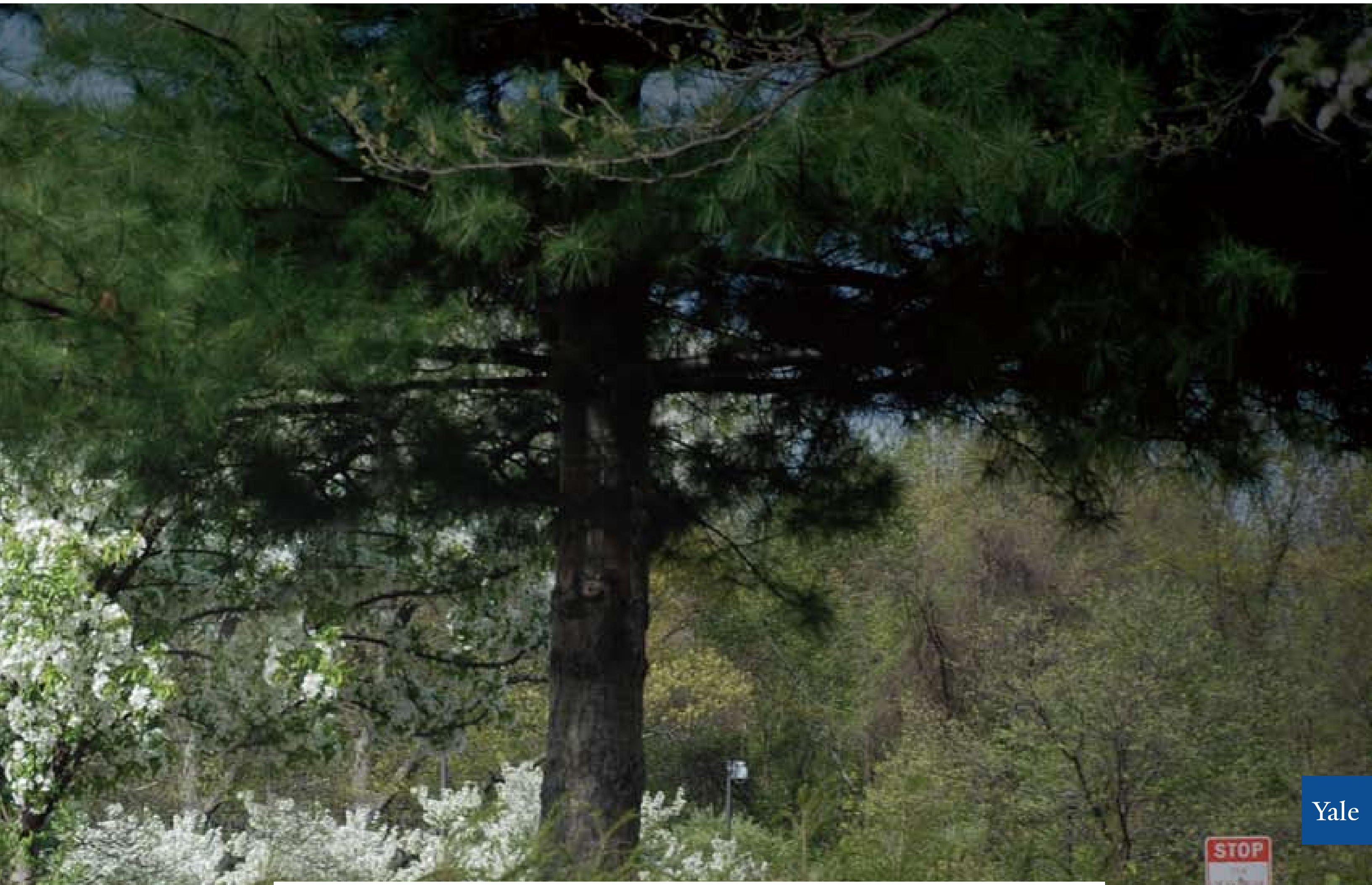
Back on the Track

Yale Bulldogs Racing Team Drives to Success

EDUCATION



The Yale Bulldogs Racing Team went back to the garage this past fall with renewed ambition and excitement to rebuild and fine-tune the Formula Hybrid race car—a high-performance gas and electric vehicle—they had built from scratch, but failed to race, the previous year.

May 2009: The first lap

In 2008-09, Henry Misas, '10, and Kamil Wasilewski, '09, decided to take on the ambitious project of designing and building a hybrid car to compete in the International Society of Automotive Engineers (SAE) Formula Hybrid competition. This would be the third year Yale competed, but first year the car would be designed and built outside of Professor John Morrell's Mechanical Design course.

While there are no restrictions on entering the same car as previous years, Misas saw huge limitations with the previous year's design. "The frame was too big and too heavy," said Misas. "It was designed to accommodate a 300 pound, seven foot tall power lifter." Misas and Wasilewski decided it was time to start from scratch.

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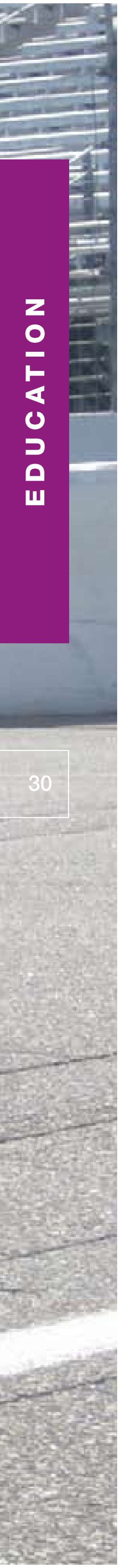

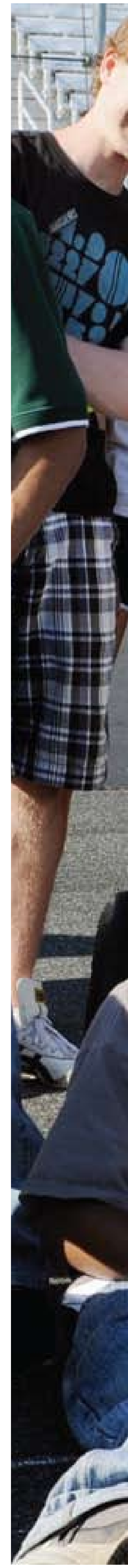

By the end of the year, their team had expanded to five and had raised $17,000—$10,000 of which came from the School of Engineering & Applied Science. While a significant amount of funding for a student organization, this was just a drop in the bucket compared to many other competitors that have industry sponsorship and significant financial support.

The team put all they had into the car—working late into the night and napping in the library. "It's all we thought about," said Misas. In the end, they couldn't pull it off. They had barely finished the car by the day of the competition and were literally too tired to make the trek to New Hampshire where they were to compete. "Even if the last two months were so exhausting, it was up there with one of the best times that I've had in my life," said Misas.

May 2010: The checkered flag

By the end of the summer break, Misas was ready to complete what he had started. The team expanded to twelve, including one non-engineering member, Kirill Miniaev, '12, who is an art major. With renewed dedication and excitement, they reworked the previous year's design—making improvements to the frame, suspension, powertrain, and electrical systems.

With a new, albeit, much smaller budget, there was plenty of opportunity for improving upon what had already been built. "We still took everything apart," said Aaron Fuchs, '10, who was responsible for the suspension design.

Following eight months of hard work and dedication, on May 3, 2010, the Yale Bulldogs Racing Team pulled into Loudon, New Hampshire, site of the SAE International Formula Hybrid Competition, with their best entry to date. Before they were able to compete, however, there were a series of hurdles to overcome.

Technical inspection begins on day one. Arriving late in the day, the team had to forgo inspections until day two. "We held our breath through every inspection," said Misas, knowing that they could not compete without passing the safety tests.

There were four tests: mechanical, electrical, tilt, and braking. While they sailed through the mechanical and electrical inspections, they failed the other two. "The fuel tank started leaking pretty profusely during the tilt test," said Misas. Fortunately, it was a relatively easy fix. The braking system, on the other hand, took a few hours to fix, but by day three, they were given the green light.

Evaluated on design, presentation, acceleration, autocross, and endurance, the Yale Bulldogs Racing Team was awarded 2nd Best Engineered Hybrid Design and finished 10th in the pack of 30. They were one of few teams that had a fully integrated drive-by-wire system, as opposed to the traditional method of mechanically connecting the gas pedal and the engine.

"The bar is set higher now for the Yale Formula Hybrid team. We are confident that Yale can win this competition and will come back next year with an even stronger car," said Misas.

We probably won't see a new car next year, but certainly a modified version of this year's entry. Their cheap, heavy batteries may be the first to go. After two years, they have learned that the eight months they have to prepare for the race go by in a flash. The team will miss the mechanical expertise and leadership of Misas and Fuchs this year, but has confidence in the incoming president, Jon Biagiotti, '11, electrical engineering major.

A special thanks goes to Yale staff Nick Bernardo, Ed Jackson, and Dave Johnson, mechanical engineering professor John Morrell, and independent carbon fiber/composites specialist, Dave Campaniello for their contributions to Yale's culture of engineering with the Yale Bulldogs Racing Team.


MOTOR
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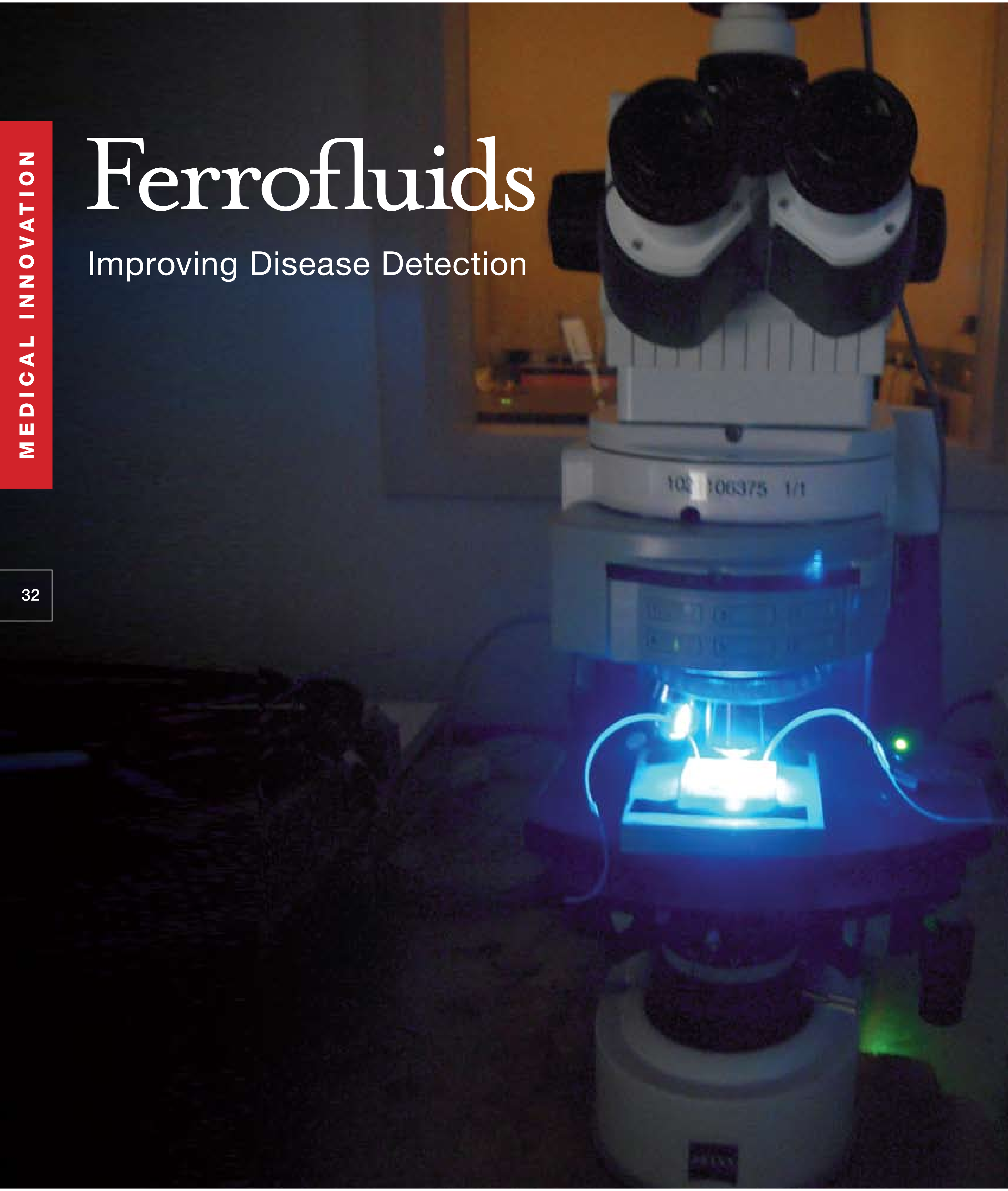

Ferrofluids

Improving Disease Detection

A team led by associate professor of electrical engineering Hur Koser has developed a way to rapidly manipulate and sort different cells in the blood using magnetizable liquids, which could dramatically improve the speed and sensitivity of tests used to detect cancer biomarkers, blood disorders, viruses and other diseases.

Ferrofluids are comprised of magnetic nanoparticles suspended throughout a liquid carrier. They have been used in industrial applications for years, including hard disk drives and loudspeakers. Koser's team has now developed a biocompatible ferrofluid—one with the right pH level and salinity so that human cells can survive in it for several hours—and has created a device with integrated electrodes that generate a magnetic field pattern, capable of manipulating and separating red blood cells, sickle cells and bacteria contained in this unique solution.

The magnetic field attracts the nanoparticles in the ferrofluid, effectively pushing and shuffling the much larger, nonmagnetic cells along specific channels. Depending on the frequency of the magnetic field they apply, the researchers are also able to manipulate and sort different types of cells depending on their size, elasticity and shape.

"It's like the cells are surfing on magnetic forces," Koser said. "When we turn on the magnetic field, the nonmagnetic cells are pushed immediately up to the top of the channel." There, they roll along the surface and can be quickly directed toward a sensor.

While other cell manipulation techniques exist, this new method is unique in that it doesn't require attaching biomarkers, or labels, to the cells and there is no need for labor-intensive preparation or post-processing.

Being able to effectively sort and move cells with this technique could allow for much greater efficiency in disease detection by directing diseased cells toward sensors. Many of today's tests require hours or even days to complete, because the concentration of diseased cells in a blood sample may be so low that it takes a long time for them to randomly bump into the sensors. In early-stage cancer, for instance, there could be one tumor cell for every billion healthy cells, making them extremely difficult to detect.

"Effective and efficient separation is very important when you're looking for a needle in a haystack," said Ayse Rezzan Kose, a graduate student in the Koser Lab. "We're hoping we can achieve an increase of several orders of magnitude in the sensitivity of existing detection technologies. If so, a blood sample analysis could be completed in minutes, not hours or days."

Koser hopes that one day the new technique will lead to portable sensors that doctors can carry into the field and which could be used to test for a range of disorders, such as cancer and HIV. "Anything you can put into the ferrofluid solution is potentially detectable in this manner," says Koser.

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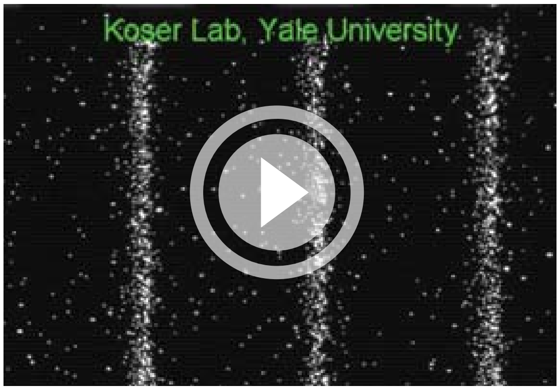

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Eye On Design

Dollar and Morrell Encourage Creativity, Invention, and Entrepreneurship

Design is a fundamental component to undergraduate engineering education, forming a bridge between analysis (i.e., "science") and application (i.e., "engineering"), and assistant professors of mechanical engineering, John Morrell and Aaron Dollar, are part of a growing effort at Yale to provide hands-on design experiences that encourage creativity, invention, and entrepreneurship.

In the Morrell Lab, researchers are using vibrations and sensory feedback to fix posture and prevent car accidents. Two seats: one for the office and one for the car have been retrofitted with cellphone motor tactors that transmit vibrations to the user's back. In the case of the office chair, they provide a reminder to sit up straight when posture needs correcting—inspired by Morrell's own back problems and difficulty remembering not to slouch at the computer. In the case of the car, vibrations as well as slight punches to the back, alert the driver to cars approaching from behind and signaling when someone is in their blind spot. According to Morrell, a driver's visual sense is already saturated, so a tactile interface with the environment may be a driver's best defense.

For Aaron Dollar designing and building a mechanical hand that can accomplish a multitude of tasks—those requiring both "precision manipulation" as well as "power grasping"—has potential applications in domestic robotic assistance as well as prosthetics, designs for which Dollar points out haven't changed much in the past 60 years. The goal is to make simple, easy-to-use devices that mimic the human hand. Dollar's creative approach earned him a place on the list of Technology Review's 2010 Young Innovators Under 35, a selection of 35 young leaders whose work is "transforming technology" and shaping the future.

"Most research efforts these days are about pushing robotics to be able to deal with the sorts of unstructured environments that humans tend to find themselves in," he says.

Dollar has extended the technology of the mechanical hand by applying it to other applications such as his Aerial Manipulator, a robot helicopter integrated with a gripper that is able to directly grasp and transport objects.

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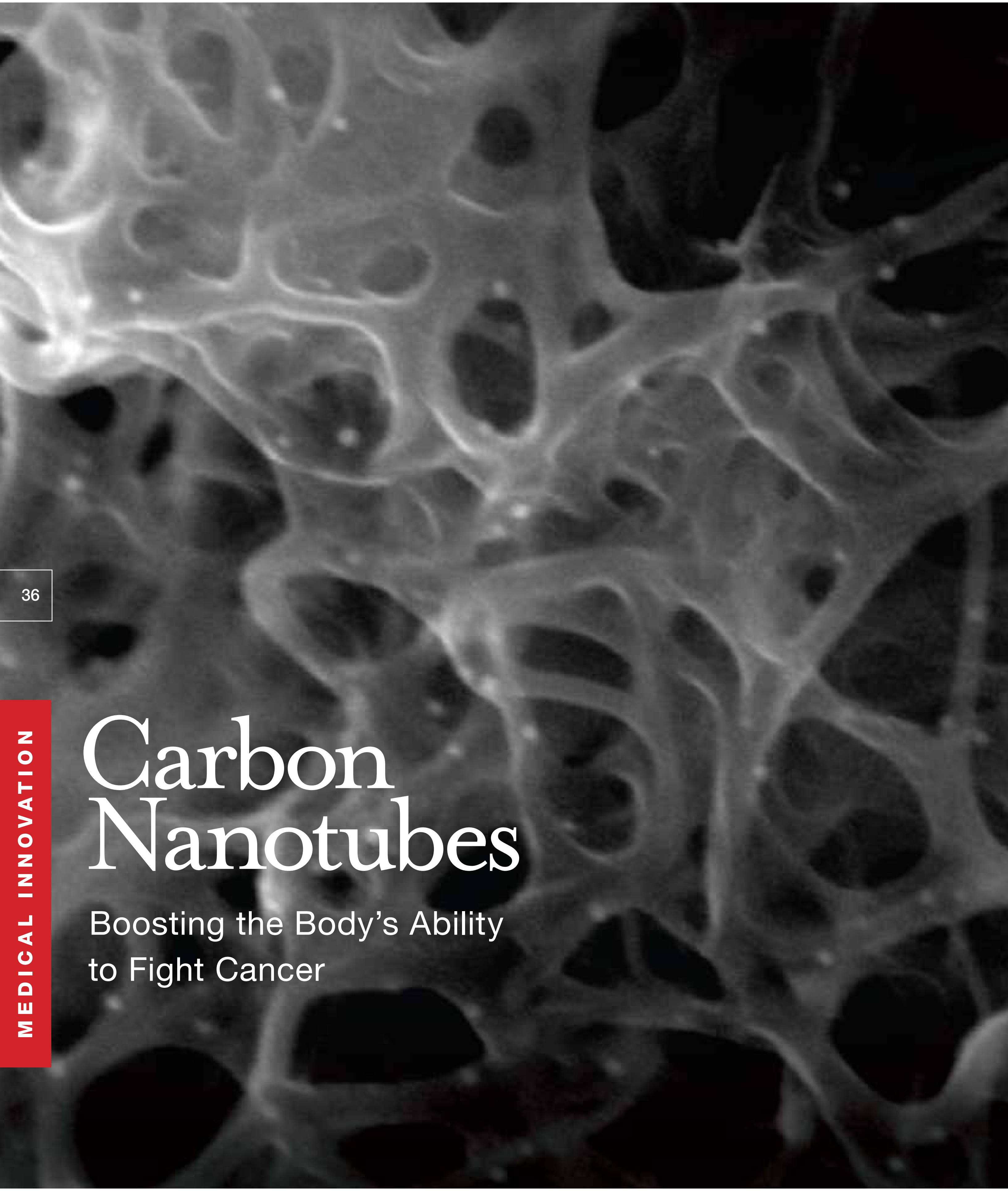
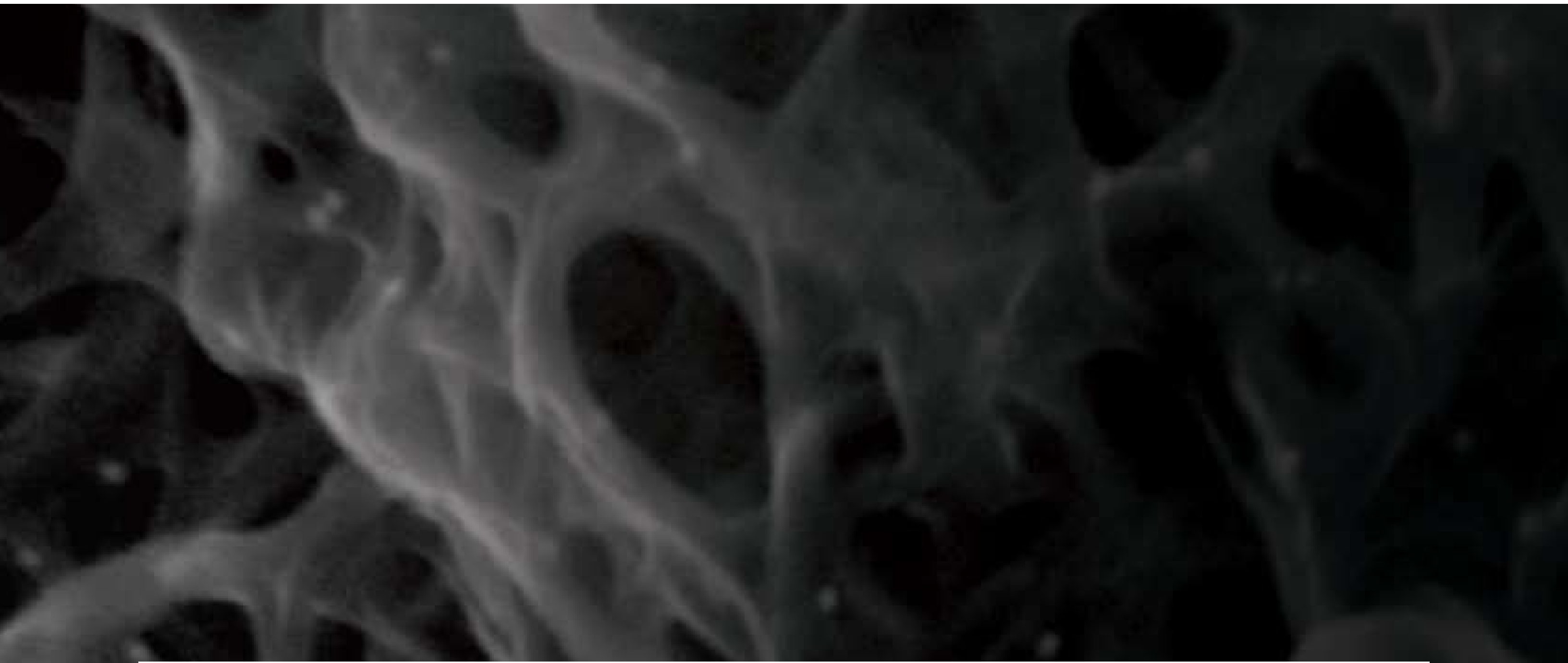


Carbon Nanotubes

Boosting the Body's Ability to Fight Cancer



An interdisciplinary team of researchers, including biomedical engineering associate professor Tarek Fahmy and chemical engineering professors Gary Haller and Lisa Pfefferle, has discovered that the defects in carbon nanotubes—cylindrical carbon molecules with novel properties and widespread applications—could improve adoptive immunotherapy, a treatment used to boost the body's ability to fight cancer. Their findings, which appeared as the cover article of the April 20, 2010 issue of the journal *Langmuir*, show that the defects cause T cell antigens to cluster in the blood and stimulate the body's natural immune response.

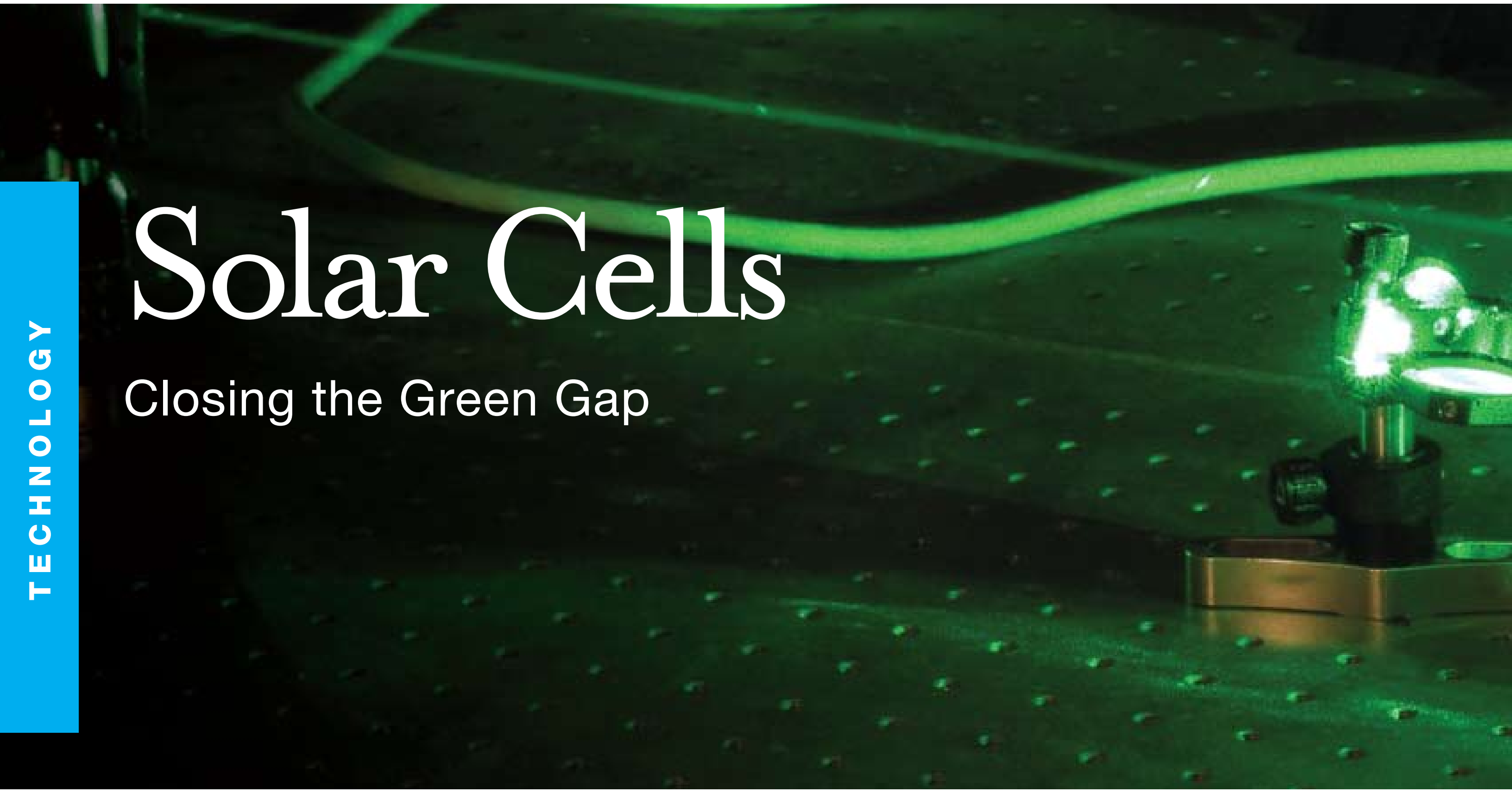
Although the body produces its own tumor-fighting T cells (a type of white blood cell), they are often suppressed by the tumor and are too few to be effective. Scientists boost the production of T cells in blood that has been drawn from a patient using different substances that encourage T cell antigens to cluster in high concentrations. The better these substances are at clustering T cell antigens, the greater the immune cell proliferation. Once enough T cells are produced, the blood is transferred back into the patient's body.

The Yale team had previously found that the antigens, when presented on the surface of the nanotubes, stimulated T cell response far more effectively than antigens on other commonly used substrates such as polystyrene, even though the total amount of antigens used remained the same. The reason, they discovered, was that the antigens clustered in high concentrations around the tiny defects found in the carbon nanotubes.

"Carbon nanotube bundles resemble a lymph node microenvironment, which has a labyrinth–like geometry," said Fahmy. "The nanotube bundles seem to mimic the physiology and adsorb more antigens, promoting a greater immunological response."

Current adoptive immunotherapy takes weeks to produce enough T cells, but lab tests showed that the nanotubes produced the same T cell concentration in just one-third the time, Fahmy said.

Carbon nanotubes can be toxic when used in the body. But this isn't the case when they are used in blood that has been extracted from the patient, Fahmy said. "We think this is a really interesting use of carbon nanotubes. It's a way to exploit the unique properties of this material for biological application in a safe way."



TECHNOLOGY

Solar Cells

Closing the Green Gap

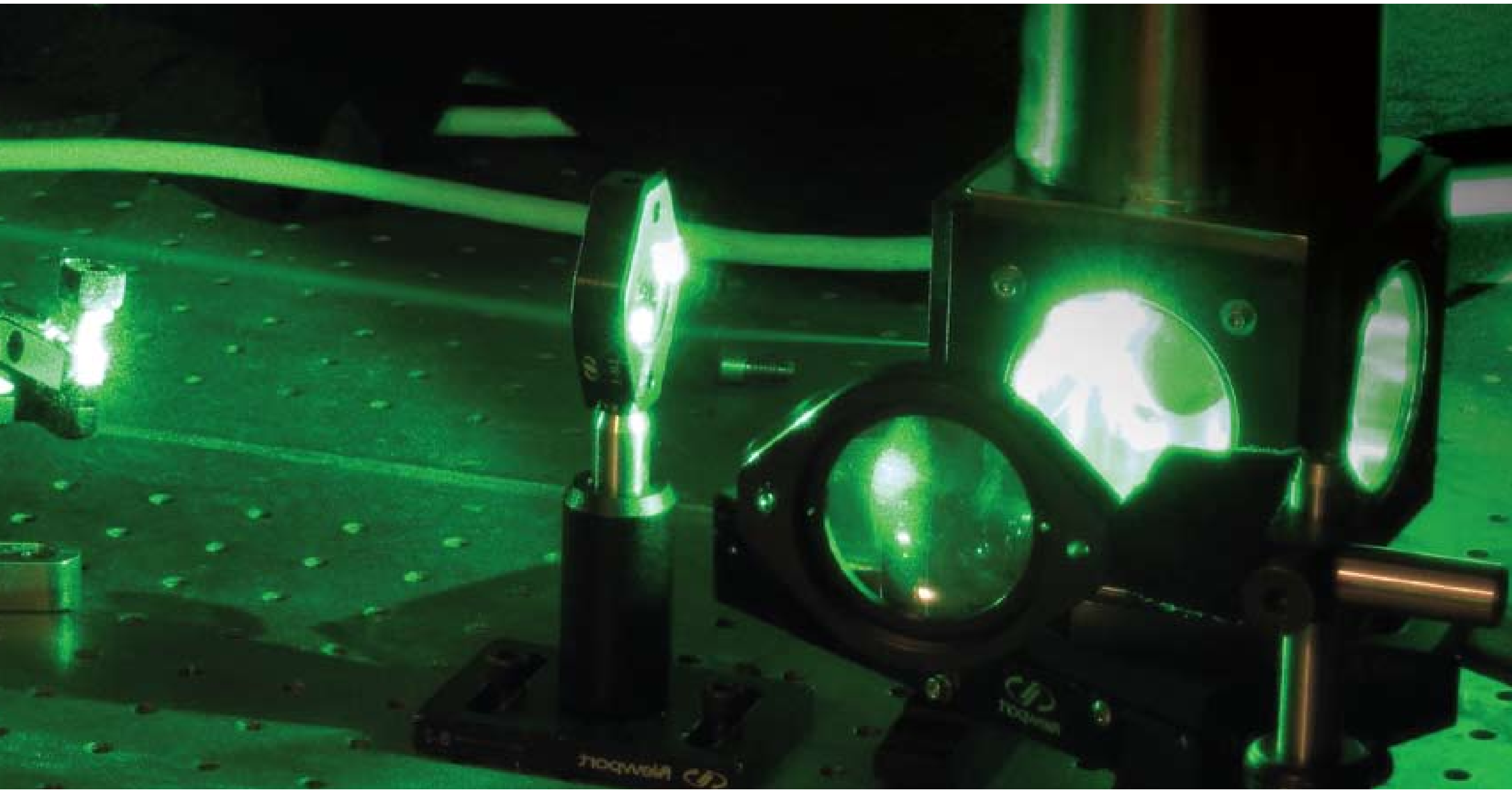
Assistant professor of electrical engineering Minjoo Larry Lee asks the students in his new class on solar cells: "Is 20% efficiency good?" He's referring to today's commercially-available silicon technology. Many of them say "yes." "I want them to say, 'No, that's terrible. Why are you throwing away so much energy?' But I think they're starting to wise-up about the reality of solar cells, which is that 20% is pretty extraordinary for silicon."

Twenty percent is by no means the limit, however. With different materials and combinations of materials, industry has successfully achieved 40% efficiencies. Theoretically, researchers believe they can reach 60% but for that they need to be able to do something that nobody has yet been able to do—harness the "green gap."

While sunlight contains all colors, the peak in the sun's radiation spectrum lies in the green range. "The problem is fundamental in nature," says Lee. "There is a missing component in the theoretical 60%-efficient solar cell—that which targets this green band of wavelengths—that cannot be made right now. And you can't reach 60% without it."

The "green gap" is the name given by engineers to the difficulties in achieving efficient green light emitting diodes, but the problem extends in a reciprocal manner to solar cells. "Although nature has given us a huge amount of green light, and even tuned our eyesight to have maximum sensitivity to yellowish-green colors, nature did not give us many semiconductors that work well in this range," Lee explains. While silicon will happily convert green light to electricity, it does so poorly—harnessing only a small amount of the light energy while losing the majority to heat.

For decades, researchers have understood that one way to improve efficiency is to utilize a combination of different solar cells wired in tandem with each cell optimized to convert a small band of the spectrum and, thereby, minimizing total energy loss. So far, industry has successfully combined five different semiconducting materials, most of which are designed to efficiently divvy up the large amounts of red-to-infrared light that shine onto the earth's surface. However, the critical yellow-green portion of the spectrum remains poorly utilized.



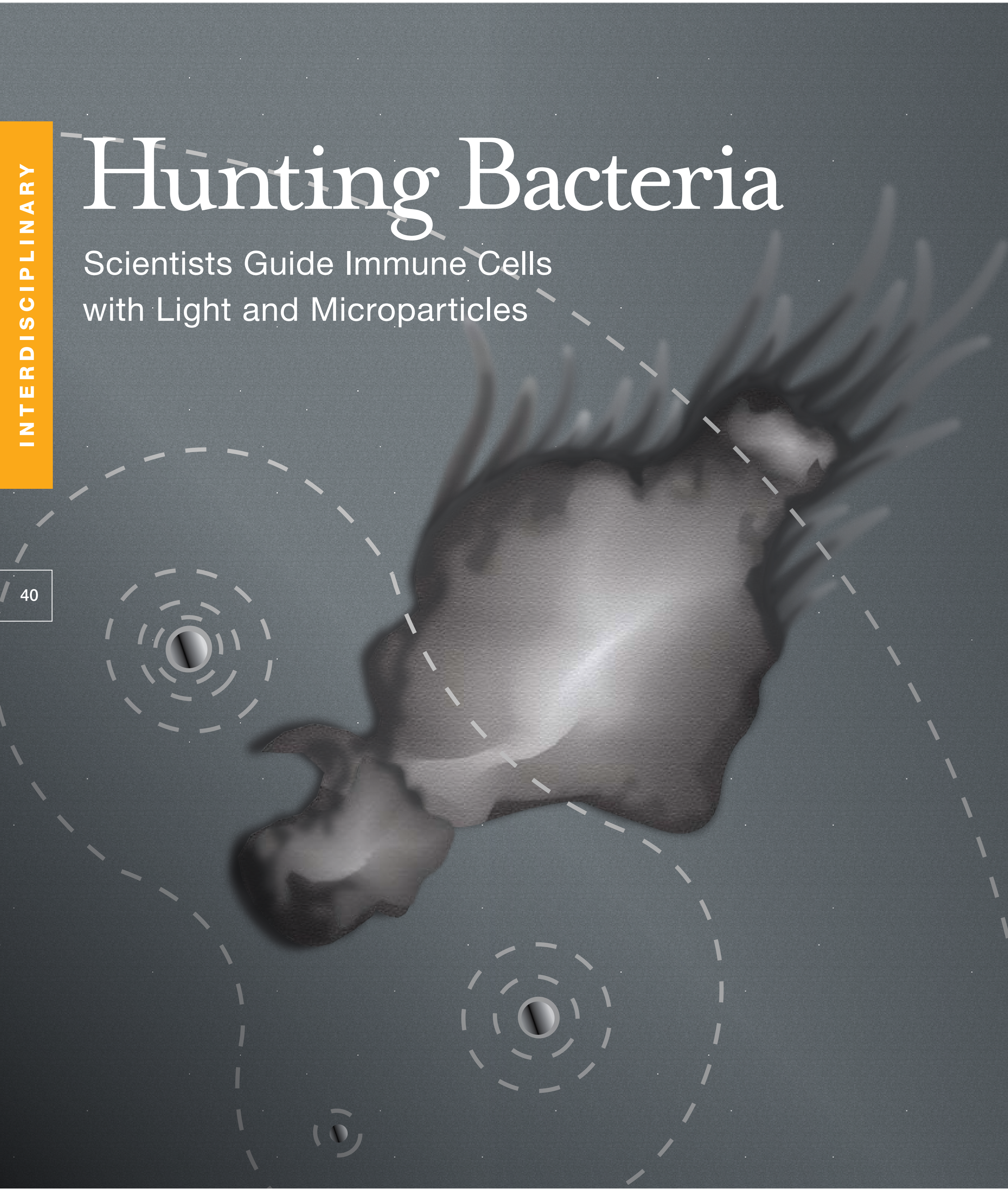
According to Lee, the final piece of the puzzle is the semiconductor alloy, indium-gallium-phosphide (InGaP). But, it will take a very precise ratio and arrangement of the three elements in a crystal lattice to effectively harness the green gap. "Unfortunately, you can't just buy customized InGaP crystals with the necessary properties," says Lee, so he and his group deposit or "grow" the material in their lab in Yale Engineering's Becton Center.

Using molecular beam epitaxy (MBE)—a method of depositing single crystals—Lee grows InGaP with atomic precision. In order to attain the property Lee is looking for—in this case, a band gap of around 2.3 electron-volts to match the energy of the incoming green photons—Lee starts with gallium-arsenide (GaAs). To this he adds phosphorous, which shrinks the space in the lattice. The smaller lattice is key to attain the precise atomic arrangements necessary in the InGaP. Finally, the InGaP solar cell structure is deposited and devices are fabricated in the Yale Cleanroom. So far, Lee's team, which includes postdoctoral associate John Simon, graduate student Stephanie Tomasulo, and Yale College senior Jonathan Biagiotti '11, has demonstrated cells which efficiently convert the amber region of the spectrum. "Next," he says, "we will demonstrate yellow cells and finally green."

Lee received an NSF CAREER Award for his research on solar cells and was on a collaborative team that set several records in solar cell technology before coming to Yale. There are two trains of thought regarding the future of solar cell technology: high efficiency vs. low cost. Unfortunately, the two don't generally go hand-in-hand. While Lee's work will undoubtedly find its primary application in the small but lucrative market of satellite-based solar cells, he believes that high-efficiency solar cells will eventually play a significant role in our energy future on Earth.

Hunting Bacteria

Scientists Guide Immune Cells with Light and Microparticles



When bacteria enter our bodies they secrete molecules, leaving behind chemical trails as they move through our system. It has been known for some time that immune cells follow these trails in order to hunt the bacteria. However, studying exactly how immune cells process these chemical signals has been challenging.

Now a team of engineers—led by Eric Dufresne, the John J. Lee Assistant Professor of Mechanical Engineering, and Holger Kress, a postdoctoral associate—has developed a way to create artificial chemical trails that can be shaped in three dimensions over time. By controlling the chemical trails, the team was able to control the movements of neutrophils—immune cells in the blood—and study how they are able to respond to these signals.

The team used sponge-like microparticles, designed in the laboratory of Tarek Fahmy, associate professor of biomedical engineering, that mimicked bacteria by slowly releasing a characteristic bacterial "scent." They then moved these microparticles using highly focused beams of light to control the pattern of released chemicals over space and time, stimulating the immune cells to respond. The neutrophils can be seen following the microparticles on videos produced by the researchers.

"By fusing recent advances in optical and materials science, we've developed a new approach to control chemical microenvironments with light," said Dufresne, who developed holographic optical tweezers—the underlying technology used to manipulate the microparticles—in the late 1990s. "Until now, people have used optical tweezers to move physical objects. We've demonstrated that they can also be used to manipulate chemical gradients."

The team used two different chemicals, one of which attracted the cells and another that repelled them, to demonstrate how they could direct the neutrophils into moving along a path, either toward or away from the microparticles. They could also examine how the cells responded when there were conflicting signals sent by several of the artificial bacteria.

Chemotaxis—the migration of cells based on chemical signals in their environment—plays an important role in a number of biological processes and diseases beyond the immune system. "Understanding how cells move in response to chemical stimuli can help us better understand how a single egg develops into a complex organism or how brain cells grow into a network of neurons in a growing embryo, or how cancer cells spread through the body," Kress said. "This technique could give biologists insight into the ways many different types of cells respond to environmental stimuli in a wide range of situations."

Yale

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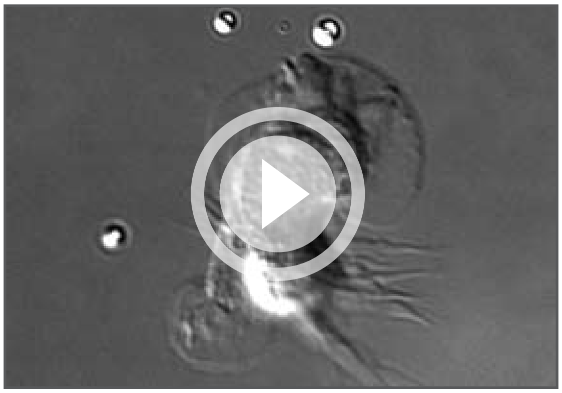

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EDUCATION

Creative Classroom

With Catapults and ATVs, Dollar Brings Practice to Theory

For most science and engineering students, the term "final exam" tends to conjure up images of caffeine-fueled, late-night cram sessions, frenzied scribbling of equations and scores of memorized theories, laws, and figures.

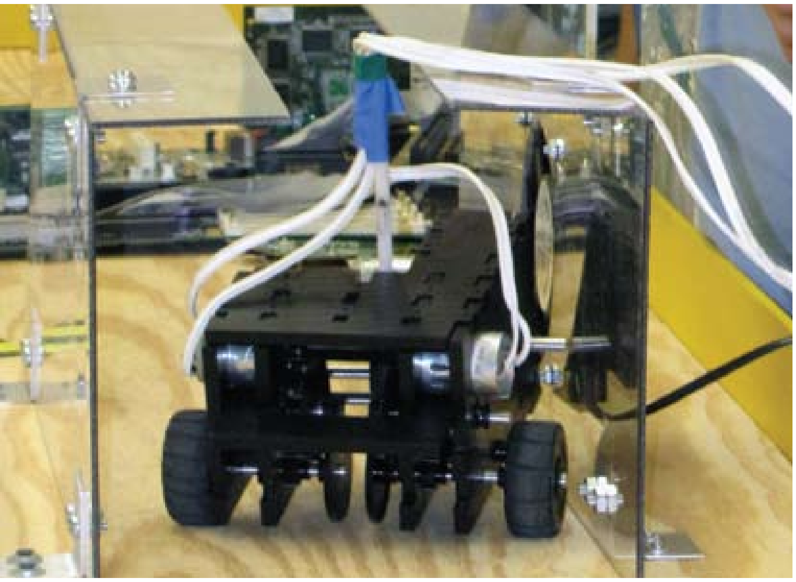
But for the students of Mechanical Design (MENG 185), the final exam consisted of driving their custom-built, remote-controlled all terrain vehicles (ATVs) through an obstacle course of tunnels, ramps, and slaloms in a spirited competition between teams of students all vying for first place.

Aaron Dollar, who taught the course for the second time this spring since coming to Yale as an assistant professor of mechanical engineering in January 2009, wanted the class to be different right from the beginning. Admitting that he himself doesn't learn well by watching someone stand at the front of the classroom writing equations on the board, he set out to teach the class—designed primarily for freshmen and sophomores considering mechanical engineering as a major—in a way that would appeal to prospective engineers.

"Engineers tend to be very hands-on, so sitting in a lecture where you're just watching someone do math on the board often isn't the best way to teach those types of people," he says. Dollar wanted to expose his small class of 15 students to what engineering is all about by teaching them not only the theory behind mechanical engineering, but how those ideas are applied in the real world. Throughout the spring semester, the class spent time in the machine shop, dissected electrical screwdrivers and computer hard drives, and designed, built and tested catapults in a competition that pitted half the class against the other to see which could launch a Tootsie Roll the farthest.

Embedded within the lab projects are the essential lessons that any mechanical engineering student needs to learn, Dollar notes. The catapult competition, which he calls "beam-bending baseball," went hand-in-hand with a section about materials and beam stresses. Designing catapults taught the students about maximum loads, stress and elasticity in a way that immediately applied what they had just learned in class.

One topic that is unique to the course is manufacturing. After lecturing about different processes used in the manufacturing industry, Dollar had the class take apart discarded computer hard drives. The students had to use their



newly acquired knowledge to figure out how the various components were created, deciphering whether stamping, forging, casting, injection molding or milling was used.

It's the kind of hands-on learning that Volkan Doda, a senior majoring in mechanical engineering and architecture, wishes he had experienced sooner in his three years in the engineering program. "The major is very theoretical. I wasn't exposed to many classes before this that were hands-on," he says. "There are some things you just have to see firsthand in order to understand."

Dollar does include two more traditional midterms throughout the semester that test the students' theoretical understanding, but it all leads up to the end-of-year ATV competition, where students get to show off their creativity as well as their grasp of fundamental engineering principles.

Using motors, switches, batteries, and other parts gleaned from the electrical screwdrivers they previously disassembled, the students were also given a 12-inch by 12-inch piece of plastic from which to cut out the car body parts and a $60 budget to buy gears. From that, they worked in teams of three or four to design and build a remote-controlled ATV that could successfully navigate the obstacle course and overcome a number of challenges that Dollar designed to test different characteristics such as torque, power, agility, and traction.

The ATVs were required to fit through a tunnel, pull a weighted cart up a ramp, pass over a rubble mound, drive over a heap of pipes, and maneuver through a slalom course. Points were awarded, along the way depending on the level of difficulty and how well each vehicle met the challenges during a five-minute time trial.

For the students, the competition has proven to be a much more fun way to end the year than with an hours-long written exam. But for Dollar, the competition has been an effective way to test the students' understanding while actively engaging them in design and building, the very heart of engineering. Finding a project that does both effectively isn't an easy task, he says. "You have to find a happy medium. If the project is too easy or too constrained they'll just copy an existing solution and won't connect to it on a deeper level. And if it's too open-ended, the students will just flounder around without making effective progress."

"The theme of the class is really that engineering design is both creative as well as being rooted in the engineering science they learn throughout the curriculum," Dollar says. "It's not a body of knowledge, per se, but a connection between the two that will hopefully provide students with the grounding they need to make them more effective engineers."

Junior Faculty Earn Top Honors

Yale Engineering is proud to announce that Eugenio Culurciello, associate professor of electrical engineering, received the 2010 Presidential Early Career Award for Scientists and Engineers (PECASE)—the highest honor bestowed by the U.S. government on outstanding scientists and engineers beginning their careers. Yale Engineering is also proud to announce that four faculty received National Science Foundation CAREER Awards which recognizes excellence in integrating research with teaching. This year's NSF CAREER Award recipients were assistant professor of electrical engineering Minjoo Larry Lee, assistant professor of chemical engineering André Taylor, associate professor of biomedical engineering Michael Levene, and assistant professor of mechanical engineering Aaron Dollar.

Dollar also earned a place on the *Technology Review* list of 2010 Young Innovators Under 35. Each year, the magazine selects 35 young leaders whose work is "transforming technology" and shaping the future. Dollar joins the ranks of Google cofounders Larry Page and Sergey Brin, Facebook cofounder Mark Zuckerberg, PayPal cofounder Max Levchin, and Linux developer Linus Torvalds.

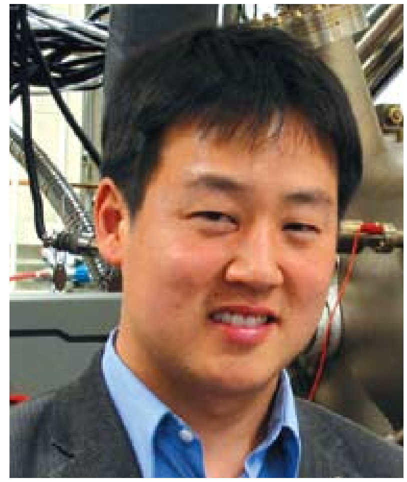
In late 2009, assistant professor of electrical engineering Hong Tang received the Packard Fellowship for Science and Engineering. This prestigious award is bestowed annually to 16 innovative researchers in the early part of their careers.

Eugenio Culurciello

Associate Professor
Electrical Engineering

Aaron Dollar

Assistant Professor
Mechanical Engineering & Materials Science



Minjoo Larry Lee

Assistant Professor
Electrical Engineering

Michael Levene

Associate Professor
Biomedical Engineering

Hong Tang

Associate Professor
Electrical Engineering

André Taylor

Assistant Professor
Chemical & Environmental Engineering

Yale

Faculty Spotlight: Jay D. Humphrey

Yale Engineering is proud to announce the arrival of Jay D. Humphrey, professor of biomedical engineering. Humphrey comes to the Yale School of Engineering & Applied Science from Texas A&M University where he served as Regents Professor and Professor of Biomedical Engineering.

Humphrey's research interests focus on diseases of the cardiovascular system, including hypertension, atherosclerosis, aortic and cerebral aneurysms, and cerebral vasospasm. He has developed mathematical models that disprove two long-standing clinical hypotheses concerning why aneurysms enlarge and rupture. He also has developed a new theory of "growth and remodeling" based on emerging ideas of mechanobiology, which he hopes will provide new insight into the natural history of diverse vascular diseases, including aneurysms, and their treatment.

Humphrey received his Ph.D. in Engineering Science and Mechanics from The Georgia Institute of Technology and completed a post-doctoral fellowship in Cardiovascular Medicine at the Johns Hopkins University. He has authored numerous textbooks and has published over 150 journal papers. He serves as the founding co-editor-in-chief for the international journal *Biomechanics and Modeling in Mechanobiology* as well as on the World Council for Biomechanics and the executive committee of the U.S. National Committee on Biomechanics. In addition, Humphrey is a Fellow of the American Institute of Medical and Biological Engineering and a Fellow of the American Society of Mechanical Engineers.

Alumni Notes

Please share with us your experiences at Yale and where you are today. Go to the web address below to link to our alumni notes page.

http://seas.yale.edu/alumninotes

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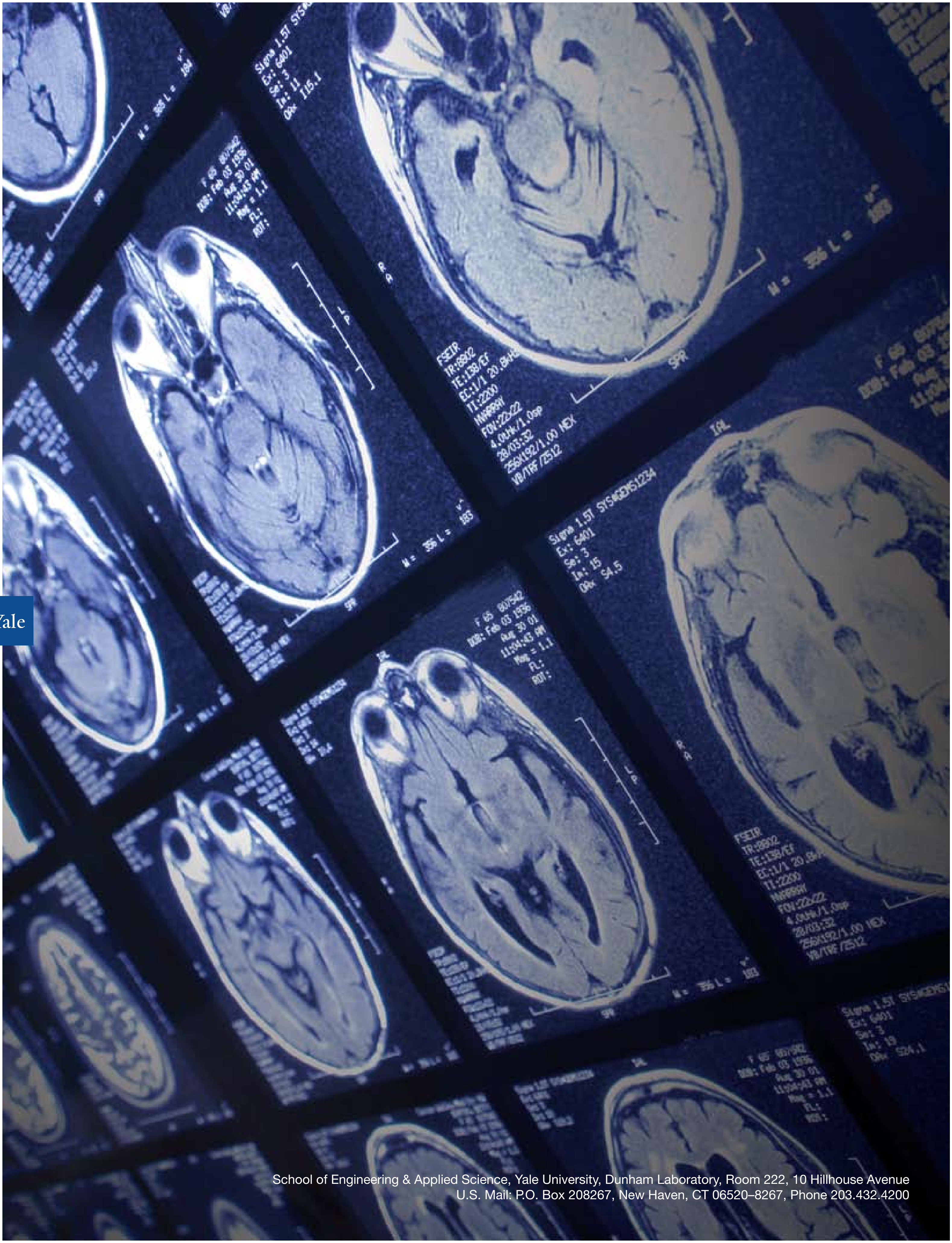
http://seas.yale.edu/give

Yale

“Highlights” for Engineers

Can you find five things that are wrong with this image?

For help, refer back to the original image on page 20.
Answers can be found at http://seas.yale.edu/highlights



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